AD-A213 704

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
Annual (1988)

4. TITLE AND SUBTITLE
UNITED STATES AIR FORCE COLLEGE SCIENCE & ENGINEERING PROGRAM Vol I of I

5. FUNDING NUMBERS
61102F
3396/D5

6. AUTHOR(S)
Dr. Danrah

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Universal Energy Systems Inc

8. PERFORMING ORGANIZATION REPORT NUMBER
AFOSR-TR- [illegible]

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/XOT
BLDG 410
BAFB DC 20332-6448

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-88-C-0053

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

SEE ATTACHED

DTIC
ELECTE
OCT 2 5 1989
S D D

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclassified	unclassified	unclassified	N/A

NSN 7540-01-280-5500

Standard Form 298 (890104 Draft)
Prescribed by ANSI Std. 239-18
298-01

89 10 24 129

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (AFSC)
NOTICE OF [illegible] TO DTIC
[illegible] reviewed and is
[illegible] AFR 190-12.
[illegible]
[illegible]
Chief, Technical Information Division

Universal Energy Systems, Inc.

UNITED STATES AIR FORCE

COLLEGE SCIENCE AND ENGINEERING PROGRAM

1988

PROGRAM MANAGEMENT REPORT

VOLUME I OF I

UNIVERSAL ENERGY SYSTEMS, INC.

Program Director, UES
Rodney C. Darrah

Program Manager, AFOSR
Lt. Col. Claude Cavender

Program Administrator, UES
Susan K. Espy

Submitted to

Air Force Office of Scientific Research

Bolling Air Force Base

Washington, DC

December 1988

TABLE OF CONTENTS

INTRODUCTION

As part of the Special Studies section of the Summer Faculty Research Program, UES initiated a College Science and Engineering Program for the Astronautics Laboratory in 1988.

The CSEP was sponsored by the Air Force Astronautics Laboratory through the Air Force Office of Scientific Research (AFOSR) and conducted by Universal Energy Systems, Inc. (UES). It provides research opportunities for qualified college students from U.S. universities or technical institutions. These opportunities consist of an eleven week research appointment with the Astronautics Laboratory, located at Edwards Air Force Base, California.

The students were selected from such fields as Analytical Chemistry, Chemical Physics, Inorganic Chemistry, Organic Chemistry, Physical Chemistry, Aeronautical Engineering, Electrical Engineering, Mechanical Engineering, Nuclear Engineering, Material Science and Physics.

The students in this program have the following specific obligations:

1) To participate in research under the direction of a laboratory scientist or engineer at the Astronautics Laboratory.

2) To prepare a report at the end of the summer period describing the summer research accomplishments.

3) To complete an evaluation questionnaire on the program.

The program objectives on the College Science and Engineering Program are as follows:

1) To stimulate among college students broader interest in careers in science and engineering specialties of interest to the Air Force.

2) To establish individual working relationships between students and active researchers.

3) To strengthen the nations efforts to recruit and sustain careers in science and engineering.

The research period of these appointments were for eleven continuous weeks, a maximum of 55 working days. The research was done at the Astronautics Laboratory between 1 June and 30 September.

The stipends for the student researchers in this program depended on the student's degree status:

Freshman	$220.00 per week
Sophomore	$232.00 per week
Junior	$260.00 per week
Senior	$290.00 per week

Travel expenses were reimbursed to the student for one round trip between the student's permanent residence and the Astronautics Laboratory in accordance with the UES travel policy.

UES received a total of 26 applications from various universities for consideration. A total of 24 students participated on the program.

APPOINTMENT LETTER

25 April 1988

* Please call UES at 1 -800 - 7532 upon receipt, during 8:00 a.m. to 5:00 p.m. EST.*

Dear :

APPOINTMENT LETTER AS SUMMER FELLOW
COLLEGE SCIENCE AND ENGINEERING PROGRAM

Universal Energy Systems, Inc (UES), under Contract F49620-88-C-0053 for the United States Air Force Astronautics Laboratory College Science and Engineering Program (CSEP), desires to obtain your services as a Summer Fellow on location at

Astronautics Laboratory
Edwards AFB, California

If you accept this adjunct vendor appointment, as indicated by your signing the statement of intent at the end of this letter and returning the letter, your services will be authorized for a continuous eleven-week period beginning no sooner than June 1 and ending no later than September 30, 1988.

UES will compensate you for time you spend in your research effort and a round trip travel expense incurred as a result of your assigned effort. However, in order for you to receive any funds, you are required to submit invoices to UES in the format described in the attached INFORMATION BROCHURE FOR SUMMER FELLOWS. ALL invoices must be countersigned by your Effort Focal Point. Your Effort Focal Point is an Air Force individual at your research location.

Your Effort Focal Point is:

The compensation rate under this appointment is fixed at for a maximum of 55 days (5 working days per week) occurring during the eleven-week research period. During this appointment period you may submit invoices for compensation at your convenience, but no more frequently than bi-weekly. Invoices for the final 2 weeks of effort will not be paid until you have submitted the final report required by this contract described in the FINAL REPORT INFORMATION BULLETIN.

All travel reimbursements under this appointment will be made under the current UES policy, as described in the brochure. Deviations from the attached budget are not authorized and will not be reimbursed. Any additional travel expenses incurred during the appointment period will be your responsibility.

In providing your services on an invoiced basis to UES, you acknowledge your status as that of an independent contractor and not as an agent or employee of UES or the contracting agency. You incur no authority to enter into any contract or to make any commitments on behalf of UES or the contracting agency. Upon receipt of your invoice for compensation, travel, UES will in turn bill the contracting agency for the exact amount of your invoice plus a General and Administrative charge. Payment on your invoice will be transmitted as quickly as possible under these circumstances. Invoices should be directed to:

Universal Energy Systems, Inc.
CSEP Office
4401 Dayton-Xenia Road
Dayton, Ohio 45432

This agreement is deemed to be in effect when you have signed it and returned it to the UES CSEP Office and, after final review, it has been signed by me. At that time UES will dispatch a copy of the signed agreement to you and it will be in effect.

Sincerely,

Rodney C. Darrah, Director
College Science And Engineering Program

RCD/mt
1837s

Copy & Return to UES

I accept the terms and conditions of this vendor appointment as outlined. I specifically recognize that invoices are processed as vendor invoices and that the payment process is as described above. I agree to submit receipts and documentation for all items invoiced and to submit a "Brief Report of Effort" along with each invoice. I certify that compensation received during the period of appointment is not concurrent with compensation received from other Federal government projects, grants, contracts, or employment and that the daily rate is within institutional allowance of outside activity permitted by my institution. I agree to submit invoices in the format required by UES. I also agree to submit my final report, including approval from my Effort Focal Point, and the program evaluation questionnaire, to UES by September 30, 1988.

DATE SIGNATURE SOCIAL SECURITY NUMBER

Copy & Return to UES

This is to certify that I have received the "Information Brochure for Summer Fellows on the 1988 USAF-UES College Science And Engineering Program," dated May 1988, and that I have read and understand the requirements and procedures outlined in it.

Date　　　　Signature

Social Security Number

I understand that I am considered a self employed vendor under the terms of this agreement. As such, I am responsible for all tax and social security obligation and insurance coverage.

Date　　　　Signature

APPOINTMENT PACKAGE

Dear Colleague:

Congratulations on your selection as a Summer Fellow on the 1988 USAF-UES Astronautics Laboratory College Science And Engineering Program!

Please find enclosed the "INFORMATION BROCHURE FOR SUMMER FELLOWS". Please read it carefully for the important facts and procedures regarding your obligations, pay, travel, reports, etc.

Your appointment on this program is directly from Universal Energy Systems, Inc. (UES) title of Summer Fellow. Your position within the Air Force laboratory/center corresponds to that of a Research Associate. This is a direct appointment from UES rather than employment by an Air Force facility.

If you have any questions regarding the operation of the College Science and Engineering Program (CSEP), please feel free to contact the undersigned or Ms. Sue Espy, Program Administrator at the UES Dayton, Ohio office 1-800-533-7532 outside Ohio or (513) 426-9876 in Ohio.

Sincerely,

UNIVERSAL ENERGY SYSTEMS, INC.

Rodney C. Darrah, Director
College Science And Engineering Program

Enclosures

RCD/mt
1837s

PLEASE READ FIRST

Dear Colleague:

SUBJECT: CSEP Direct Appointment Packet

Enclosed in this packet are several official UES College Science and Engineering Program documents which require your action before your appointment can be finalized. These must be completed by you and returned to UES before UES will assume any financial responsibility to you on your CSEP appointment.

The first and most important of these is your appointment letter. You must sign and date it and enter your Social Security Number in the space provided at the bottom of the back page. You must then return it to UES before your appointment can be made official.

The second document requiring your immediate attention is the Budget Memorandum. This will establish the 1988 CSEP budget covering your appointment. With this Budget Memorandum is a budget form with some items already filled in. You must complete the travel section on this budget form as described in the Budget Memorandum and return it to UES for approval before UES will reimburse you for any allowable travel expenses incurred under your CSEP appointment. Return this Budget form with your appointment letter.

The third document requiring your action is a single sheet on which you must certify by your signature that you have received and read the "Information Brochure for Summer Fellows on the 1988 USAF-UES College Science And Engineering Program" included in this packet, and that you understand the requirements and procedures outlined in it. This signed sheet must also be returned to UES. Keep the Information Brochure for reference during the summer.

Return the three documents to the following address:

Universal Energy Systems, Inc.
CSEP Office
4401 Dayton-Xenia Road
Dayton, OH 45432

If you have any questions about the listed requirements or about any feature of the described CSEP material in this packet, please contact the undersigned or Ms. Sue Espy, Program Administrator at 1-800-533-7532 outside Ohio or (513) 426-9876 in Ohio.

Sincerely,

UNIVERSAL ENERGY SYSTEMS, INC.

Rodney C. Darrah, Director
College Science And Engineering Program

RCD/mt
1837s

BUDGET MEMORANDUM

TO: All Summer Fellows
FROM: Rodney C. Darrah, CSEP Director
DATE: May, 1988
SUBJECT: 1988 CSEP Budget

Attached is a partially completed budget for your 1988 CSEP appointment which we ask you to complete according to the following instructions and return to UES. Note that the budget is complete except for the travel budget and final totals. The travel budget has not been completed for your because you have two options on how you may complete this travel: (1) use of common carrier or (2) use of your private auto. The private auto mode of travel is strongly recommended due to the convenience of having an auto at your research location.

If you choose to drive your own vehicle on this trip, estimate the total round-trip mileage you will drive and enter that figure in the appropriate blank under "Travel by Private Auto". Then multiply that figure by $0.20 and enter the dollar amount in the appropriate space at the right under "Travel by Private Auto".

If you choose to travel by way of common carrier, call your selected carrier and request the rate for round trip coach fare between your home and your assigned research location. Itemize the rate and write the total in the appropriate space beside "Travel by Common Carrier". If your travel will be a mixture of common carrier and private auto, enter the estimated figures as described in both of the above cases.

UES has arranged with a travel office in Dayton, Ohio, to have the Air Fare costs of your travel on the CSEP charged directly to UES. For you to take advantage of this, you must call this travel service. The number in Dayton, Ohio is (513) 293-7444 or 1-800-628-6668. You must give the code SLI3 to have the tickets charged to UES.

The trip is for travel to your assigned research location for the 11 week research period and return. Except for the mileage or travel fare, expenses incurred enroute to the research location and return for the summer research period are not reimbursable. Hotel/Motel, meals, gas, etc., are not reimbursable.

After completing the above steps, please enter your name and address in the space provided in the upper left corner of the sheet, enter your research period starting date, sign and enter your social security number on the indicated blank at the bottom left corner, and return the budget sheet to UES with your appointment letter.

Your budget will be approved and returned to you. Along with your approved budget you will receive a Final Report Information Bulletin and Questionnaire Form. The approved Final Report and completed questionnaire form must be submitted to UES by 30 September 1988.

Copy & Return to UES

TENTATIVE BUDGET FOR APPOINTMENT AS UES SUMMER FELLOW

______________________	Astronautics Laboratory
Name	Laboratory/Center
______________________	Edwards AFB, CA
Address	Location
______________________	______________________
	Research Period Starting Date

BUDGET ITEM

1. Time compensation:

   (55 days at $/////////

2. Travel (50 miles outside area of residence)

   Summer Research Period: (50 Miles Outside Area of Residence)
   Travel by Common Carrier: (Coach Fare or less) . . ________

   Travel by Private Auto: (_____miles at 20¢/mile) . . . ________
   (Travel miles are round trip)

3. TOTAL . . . . $________

4. Total invoicing under your appointment may not exceed: $________

Effort Focal Point:

____
Signature

____
Social Security Number

INFORMATION BROCHURE

for

SUMMER FELLOWS

on the

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

May 1988

TABLE OF CONTENTS

I. SUMMER FELLOW OBLIGATIONS

Universal Energy Systems, Inc. (UES) is required by contract to impose certain obligations on you in your status as a Summer Fellow. This section outlines those obligations, and you should read them thoroughly. Your are required to sign and return the statement of understanding before the final processing of your appointment can be completed. The following is a list.

1. Research Goals and Objectives: A statement of research objectives must be provided to UES PRIOR TO the start of the summer research period. It should outline your goals and the approach you intend to follow in researching these goals. Travel expenses will not be reimbursed until after receipt of your statement of research objectives. The report should also clearly indicate the date of your first working day of the summer research period.

2. Final Report: At the end of your summer research effort, you are required to submit to UES a completed, typewritten scientific report stating the objectives of the research effort, the approach taken, results, and recommendations. Information on the required report format will be sent to you with a "FINAL REPORT INFORMATION BULLETIN" and sample report illustrating a suggested format. The final report must first be approved by your Effort Focal Point and then transmitted so as to reach UES by Friday, September 30, 1988. Payment of "Compensation" for the final two weeks of your eleven-week research period cannot be made until UES has received and approved this report in the required format.

3. Program Evaluation Questionnaire: You will be sent a critique form to complete near the end of your research period regarding your impressions of the program. This critique form should be completed and returned to UES, along with your final report, by Friday, September 30, 1988. The return of this form is a program requirement; it also must be received by UES before the final compensation payment can be made.

4. U.S. Air Force - Summer Fellow Relationship: The U.S. Air Force and UES understand and agree that the services to be delivered by Summer Fellows under this contract will be non-personal services and the parties recognize and agree that no employer-employee or master-servant relationships will exist between the U.S. Air Force and the Summer Fellows. Non-personal services are defined as work performed by an individual who is responsible for an end item, such as a report, free of supervision of the U.S. Air Force and free of an employer-employee relationship.

As a Summer Fellow, you will not:

(a) Be placed in a position where you are appointed or employed by a Federal Officer or are under the supervision, direction, or evaluation of a Federal Officer, military or civilian.

(b) Be placed in a staff or policy-making position.

(c) Be placed in a position of command, supervision, administration, or control over Air Force military or civilian personnel or personnel of other contractors or become a part of the U.S. Air Force organization.

The services to be performed under the CSEP do not require UES or the Summer Fellow to exercise personal judgement and discretion on behalf of the U.S. Air Force; rather, the Summer Fellows will act and exercise personal judgement and discretion on their research programs on the CSEP conducted by UES.

The Air Force will have unrestricted use of and access to all data developed during the period of this appointment.

II. ALLOWABLE TRAVEL EXPENSES

If you live outside of the area (50 miles) where you will be assigned for the summer program, the CSEP provides potential funding for the trip between your home and your assigned research location. As soon as you have signed and returned your appointment letter along with the budget sheet, you will be authorized to receive reimbursement for travel expenses as described below.

You are expected to make your own arrangements for this trip, and after the trip you may invoice UES for reimbursement of allowable expenses in the format described in the Instructions for Invoicing for Compensation and Reimbursement section of this brochure. Closely coordinate your travel plans with your EFFORT FOCAL POINT.

All travel reimbursements under Summer Fellow appointments are made according to current UES policy, and deviations from the approved budget are not authorized and will not be reimbursed. In light of these restrictions, you may choose either to travel by common carrier at coach rates or less, by driving your private auto, or by a combination of both. With any of these choices you may claim reimbursement up to the amount for the most direct routing, taking into the account the desirability of routing on interstate highways if you drive your private auto.

Reimbursement for direct route travel by common carrier will be paid on your submission of an invoice to UES following the invoicing instructions referenced above. In the view of the convenience of having a car at the research location, UES strongly recommends that a private auto be used for travel when practical. Reimbursement when you drive your private auto is at the rate of 20¢ per mile within the above routing restrictions and will be paid on submission of a suitably prepared invoice. These reimbursements cannot be extended to cover travel by your family if they accompany you on either of these authorized trips.

These items above are the only reimbursable travel allowances authorized under the CSEP appointment. Any additional travel expenses incurred during the appointment period will be your personal responsibility.

UES has arranged with a travel office in Dayton, Ohio, to have the air fare costs of your travel on the CSEP charged directly to UES. For you to take advantage of this, you must call this travel service. The number in Dayton, Ohio, is 293-7444 or 1-800-628-6668. You must give the code SLI3 to have the tickets charged to UES.

III. INSTRUCTIONS FOR INVOICING FOR COMPENSATION AND REIMBURSEMENT

Attached is a copy of the Invoice Format that you are required to use to obtain compensation or reimbursement from UES. Note that all disbursements by UES for compensation, travel, and/or other expenses are subject to audit approval, so you must submit receipts substantiating charges invoiced.

In addition, you must prepare, sign, date and attach to each completed invoice a Brief Report of Effort

A. PREPARATION OF BRIEF REPORT OF EFFORT

Whenever you submit an Invoice for reimbursement to UES you must also include a brief report describing your activities for the invoice period. To meet this obligation, you must prepare, date, sign, and attach to your completed invoice a Brief Report of Effort describing the research accomplished on the appointment and explain any travel during the invoice period.

This report should describe innovative techniques and designs or discoveries which may be disclosed as patents. Rights to any inventions or discoveries shall reside with UES unless determined otherwise by the contracting agency.

The Brief report should never exceed one typewritten page and most often should be considerably shorter than one page.

B. PREPARATION OF INVOICE FORMAT

The financial items required on the Invoice Format are for COMPENSATION AND TRAVEL.

Item (1) SOCIAL SECURITY/MAILING ADDRESS

Fill in your name, social security number, and address to which you wish to have your check mailed.

Item (2) COMPENSATION

(a) Indicate the dates for which you are claiming compensation, and indicate the number of days you are claiming for compensation.

(b) Multiply this number by the stipend and enter the total dollar amount in the blank total charges for service. The accumulated total number of days you claim on this appointment may not exceed the number authorized in your appointment letter.

Item (3) TRAVEL

(a) Under the heading Date indicate the date you departed on your trip and the date you arrived at your destination. If you are invoicing for a round trip, also list the date you departed on your trip and the date you arrived home.

(b) Under the heading Dept/Arrival Time list the departure and arrival times for the corresponding days you listed under Date.

(c) List your destination under the heading Destination.

(d) Under the heading Mode, indicate your principal means of conveyance; i.e., commercial air, private auto, etc

(e) Under the heading Amount, itemized these expenditures for travel reimbursement. Continue them on a separate sheet if necessary.

(f) Total these travel items and enter the dollar amount for travel in this invoice on the line to the right of Total Travel Expense.

Item (4) INSTRUCTIONS

You may combine reimbursement requests for compensation, travel, in the same invoice. The total for all items invoiced should be indicated on the blank on the right hand side of line 5.

If you have arranged your travel through the UES travel office as described on page 4, please indicate the cost of the tickets on this line.

IMPORTANT: Indicate in the space provide on each invoice the address to which you want the check mailed.

You must sign and date your invoice in the lower left hand corner as "Summer Fellow" before it is submitted; you MUST also have your Effort Focal Point countersign the invoice before it is mailed to UES Your Effort Focal Point is an Air Force individual at your research location who will be identified prior to your effort start date.

Invoices should be mailed to:

Universal Energy Systems, Inc.
CSEP Office
4401 Dayton-Xenia Road
Dayton, Ohio 45432

IV

BILL FOR SERVICE

1. ______________________________ ________________________
   Name (First, Initial, Last) Social Security #

   ____
   Address (Street, City, Zip)

   SERVICE: CSEP Summer Fellow

   SERVICE AUTHORIZED BY: Rodney C. Darrah

   RATE AUTHORIZED: //////////////////////////

   This service is for:
   Government Contract: Project # 210
   Government Contract No. F49620-88-C-0053

2. DATES OF SERVICE: ________________ TOTAL DAYS OF SERVICE ______

   TOTAL CHARGES FOR SERVICE: ____________

   ADDITIONAL ITEMIZED REIMBURSABLE EXPENSES:
   (receipts required for expenditures over $25.00)

3. TRAVEL: DATE ______________ DEPT/ARRIVAL TIME ____________

   DESTINATION_______________MODE___________AMOUNT_____________

4. TOTAL AMOUNT OF BILL: __________________

5. AIR FARE TICKETS CHARGED DIRECTLY TO UES. AMOUNT: $____________

____ ________________
Summer Fellow Signature - Date Telephone

Invoice Approval: ________________________________
Effort Focal Point Signature

X_____________________________________
Type or Print Name

Brief Report of Effort
Attached __________

Location: ______________________________

Telephone: __________________ Date: _____________________

Send bill to:
UNIVERSAL ENERGY SYSTEMS, INC.
ATTN: CSEP Office
4401 Dayton-Xenia Road
Dayton, Ohio 45432

In order for UES to provide quick turn around of your bills for service, we request your assistance in complying with the following schedule. The dates indicated are the dates your bills MUST be at UES. Please allow adequate mailing time for UES to receive your bills by the dates indicated

DATES BILLS MUST BE AT UES	DATES CHECKS WILL BE MAILED
April 7, 21	April 15, May 2
May 6, 23	May 16, 31
June 8, 23	June 15, 30
July 7, 21	July 15, Aug. 1
August 8, 23	August 15, 30
September 8, 22	September 13, 50
October 6, 21	October 17, 31
	November 15, 30

For bills received on or before these dates, UES will be able to process checks to you in the mail by the 15th and 30th. For bills received after these dates, the checks may not be processed until the next pay period, causing a two week delay in your receiving your check.

Your bill may be for any period of time. It does not have to start on a Monday or end on a Friday. Your bill may be for any period convenient for you to meet our billing dates listed above. Please note these are the dates the bill must be at UES. For example, a bill received on or before April 7 will be mailed out to you on April 15. A bill received on April 8 will not be mailed until the April 25 bills are processed on May 2.

1837s

TO: Summer Fellows on the 1988 USAF-UES College Science and Engineering Program

Dear Colleague:

Attached is the Final Report Information Bulletin and Questionnaire. The Final Report and Information Bulletin describes the standard format for your final report. Please read carefully and follow directions for the preparation of your report.

The approved Final Report and completed Questionnaire must be submitted to UES by 30 September 1988.

Thank you.

Sincerely,

UNIVERSAL ENERGY SYSTEMS, INC.

Rodney C. Darrah
Director
College Science and Engineering Program

Attachment

RCD/mt
1857s

<u>FINAL REPORT INFORMATION BULLETIN</u>

to

SUMMER FELLOWS

on the

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

MARCH 1988

COLLEGE SCIENCE AND ENGINEERING PROGRAM

TYPIST CHECKLIST

- ________ Typewritten Original
- ________ Used 1-1/2 spaces or double spacing between lines
- ________ Set 1-1/4 inch margins
- ________ Did NOT use script and did NOT use italicize
- ________ Used 8-1/2 x 11 paper
- ________ Typed on one side of the paper
- ________ Did NOT type page number on report
- ________ Wrote (in pencil) name and page number on back of each page
- ________ Report must not exceed 20 pages
- ________ All hand-lettered symbols and equations in black ink
- ________ Numbered equations at right margin
- ________ All figures done correctly in black ink
- ________ Title page; information rechecked
- ________ Abstract page
- ________ Acknowledgement page
- ________ Introduction
- ________ Objectives
- ________ Bulk
- ________ Recommendations
- ________ All sections numbered sequentially
- ________ Reference Page
- ________ Did NOT staple or bind report
- ________ PREPARED AND INCLUDED EVALUATION QUESTIONNAIRE

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

FINAL REPORT PREPARATION

I. GENERAL:

Your final report is to be included along with final reports prepared by the other Summer Fellows in a set of reports. Therefore, a standard format for these reports is required; this Bulletin outlines that standardized format. Except for unusual circumstances, your report should be less than 20 total pages long including title page, abstract, acknowledgement page, references and figures. If you encounter any problems requiring information beyond the instructions in this Bulletin, do not hesitate to call the CSEP Office at 1-800-533-7532 for help in resolving your problem.

An Evaluation Questionnaire must also be submitted at the same time as your final report.

II. THE SCHEDULE:

As indicated on page one, of the "INFORMATION BULLETIN for SUMMER FELLOWS on the 1988 COLLEGE SCIENCE AND ENGINEERING PROGRAM," dated March 1988, which you received with your appointment letter, your final report must be approved in writing by your Effort Focal Point and then be submitted in final typewritten form as described herein so as to reach

UNIVERSAL ENERGY SYSTEMS, INC.
CSEP Office
4401 Dayton-Xenia Road
Dayton, Ohio 45432

by the deadline of Friday September 30, 1988. Your submission by this date is required for UES to meet the contract schedule for compiling and delivering these reports to the sponsor, the Air Force Office of Scientific Research. PLEASE NOTE: In order to insure appropriate attention in meeting this deadline, compensation payment for the final two weeks of your eleven-week research period will not be made until UES has received and approved this final report in the required format and also received your completed Evaluation Questionnaire.

III. REPORT ORGANIZATION:

The sponsor requires that your report contain a statement of the objectives of your research effort, the approach taken to meet these objectives, the results obtained from each approach, and appropriate recommendations based on these results. To facilitate the use of the final report, a recommended format is illustrated under Appendix A of this bulletin titled "FINAL REPORT ORGANIZATION."

IV. REPORT PREPARATION:

In its final form for submission to UES, your report should be typewritten, except as noted in the following subsections, on white 8-1/2 x 11 paper. Allow a 1-1/4 inch margin on each side of the page. DO NOT use script or italicized typestyle. Type only on one side of each sheet, and use 1-1/2 spaces or double spacing between lines. Do NOT staple your report as stapling causes marks on the printer's copies. Do NOT put page numbers on your reports; UES personnel will handle this. However, write lightly in pencil your name and page number on the back of each page. Appendix B shows a good example of a final report. Study it carefully for format information. Use the Typist Checklist in front of this Bulletin for a final check before sending us your report.

A. Symbols, Greek Letters, and Equation. In the interest of facilitating the typing of your final report, you should consider hand lettering all symbols, Greek letters, and equations. Any hand lettering must be done legibly in black ink, and all important equations should be numbered sequentially at the right margin.

B. Figures and Tables. You should neatly draw and hand letter all your figures in black ink so that they are meaningful and informative to your readers. Sequentially number your figures at the bottom and include a descriptive caption there also.

C. Footnotes and References. Follow the examples of the footnotes and references shown in Appendix B.

V. PUBLISHING YOUR WORK:

You are encouraged to publish the results of your work in conference proceedings or in professional journals, as appropriate. However, the sponsor requires that an acknowledgement of sponsorship be included in all manuscripts submitted for publication.

Specifically, this acknowledgement will read as follows:

"Research sponsored by the Air Force Office of Scientific Research/AFSC, United States Air Force, under Contract F49620-88-C-0053. The United States Government is authorized to reproduce and distribute reprints for governmental purposes notwithstanding any copyright notation hereon."

In addition, the following notation will accompany each submission for publication:

"This manuscript is submitted for publication with the understanding that the United States Government is authorized to reproduce and distribute reprints for government purposes."

Further, any news releases, interviews, and all other public statements referring to research sponsored by AFOSR will acknowledge as

the supporting agency the Air Force Office of Scientific Research/Air Force Systems Command, United States Air Force.

VI. REPORTING INVENTIONS:

If you develop any patentable item during the course of your research, you are required by the sponsor and the Armed Services Procurement Regulations to submit an Abstract of New Technology. This abstract must be submitted with your final report, but as a separate document, and will be prepared in reproducible condition on 8-1/2 x 11-inch bond. A one inch space will be left blank at the top (short side) of each sheet with side margins of 1-1/2 inch. The abstract will contain:

A. Title. A short, meaningful title specifically identifying the nature of the item.

B. Graphics. Any graphics which might aid in illustrating the item and how it functions (illustrated by drawings, sketches, photographs, numbers, and descriptive names, if possible).

C. Description. Sufficient information to enable a person knowledgeable in the field to determine quickly, from a cursory inspection, the principal structural elements and function as well as the results afforded thereby.

D. Source. A reference to the source of information should be designated as follows:

Your name as inventor, plus associates as appropriate.

UNIVERSAL ENERGY SYSTEMS, INC.

4401 Dayton-Xenia Road

Dayton, Ohio 45432

Contract F49620-88-C-0053

E. Publication. Identification of the date and identify of any public use or publication of such item made by or known to you or of any contemplated publications by you, including, but not limited to, published reports, patent application, or journal articles.

F. Notice. Add the following warning at the bottom of the first page of the abstract of New Technology:

> "This document was prepared under the sponsorship of the Air Force. Neither the US Government nor any person acting on behalf of the US Government assumes any liability resulting from the use of the information contained in this document or warrants that such use will be free from privately owned rights."

A P P E N D I X   A

FINAL REPROT ORGANIZATION

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

Sponsored by the

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

Conducted by the

Universal Energy Systems, Inc.

FINAL REPORT

(INSERT TITLE HERE, UNDERLINED)

Prepared by:	(Enter Summer Fellow's Name here)
Academic Rank:	(Enter Summer Fellow's academic rank here)
Department and University:	(Enter Summer Fellow's department and university here)
Research Location:	(Enter laboratory/center, division, branch, and group, as appropriate, with which Summer Fellow accomplished research)
USAF Researcher	(Enter name of individual at research location with whom Summer Fellow most closely collaborated)
Date:	(Enter date report was prepared)
Contract No:	F49620-88-C-0053

(COMMENTS: This title page will contain only the information indicated on this sheet. This information not in parentheses will be the same on all reports; the information in parentheses will be unique to each report).

(ENTER TITLE HERE, UNDERLINED)

by

(Summer Fellow's Name)

ABSTRACT

(The Abstract should be limited to a 100-200 word summary of the report, all contained on this single page).

I. INTRODUCTION: (This section is required in all reports. It should contain one or more pages of background information on your particular abilities, and the nature of the USAF research area that resulted in you being assigned to the laboratory involved in the research).

II. OBJECTIVES OF THE RESEARCH EFFORT: (This section is required in all reports. It should list the preliminary goals you and your USAF Research Colleague arrived at as well as any goals added during the course of your research effort).

III, IV, V, etc.: (These sections contain the bulk of your report and must include:

a. The approach(es) taken in realizing each of the above listed objectives.

b. The results of each approach taken.

VI. RECOMMENDATIONS: (This section is required in all reports. NOTE: THE NUMBER OF THIS SECTION FOLLOWS SEQUENTIALLY FROM THE PRECEDING SECTION.

This section should present:

a. Guidance for implementing, where appropriate, the results of your research.

b. Suggestions for follow-on research. If you intend to apply for a mini grant, this section can include information supporting such follow-on work, provided such inclusion is consistent with and pertinent to your development in previous sections.

c. Any other suggestions having a bearing on the research you accomplished.

ACKNOWLEDGMENTS

(Appropriately-worded comments should be made acknowledging support and assistance of organizations and individuals. As a minimum, acknowledgement should be made of the sponsorship of the Air Force Systems Command, Air Force Office of Scientific Research, and the laboratory/center where you worked).

REFERENCES

(List your references using the following examples as guides:

Conference and journal publications:

1. Miller, R.N., P.T. Gliuski, and A.S. Gilmour, Jr., "A Facility for testing High Power DC, AC, or Pulsed Devices," Proc. IEEE International Pulse Power Conference, Texas Tech University, Lubbock, Texas, November 1976, pp. IIE7-1 IIE7-6.

Textbooks:

2. Kamash, Terry, Fusion Reactor Physics, Ann Arbor, Michigan, Ann Arbor Science Publishers, 1975.

SAMPLE

1986 USAF-UES SUMMER FACULTY RESEARCH PROGRAM

GRADUATE STUDENT RESEARCH PROGRAM

Sponsored by the

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

Conducted by the

Universal Energy Systems, Inc.

FINAL REPORT

Prepared by: Vito G. DelVecchio, Ph.D.

Academic Rank: Professor

Department and University: Biology Department, University of Scranton

Research Location: USAFSAM/EKLM
Brooks AFB
San Antonio TX 78235

USAF Researcher: Ferne K. McCleskey

Date: 28 Aug 86

Contract No: F49620-85-C-0013

Cloning of *Mycoplasma* Genomic Libraries in *E. Coli*

by

Vito G. DelVecchio

ABSTRACT

Genomic DNA of *Mycoplasma hominis* and *Ureaplasma urealyticum* was digested into fragments by Pst I. These restriction digests were combined with and ligated to pBR322. The recombinant DNA was used to transform HB5 *E. coli* cells. *E. coli* clones containing mycoplasmal inserts were isolated with the aid of Ampscreen, which colorimetrically assays for B-lactamase. *E. coli* cells containing lnserts of mycoplasma DNA will not have B-lactamase activity, since the mycoplasma DNA is inserted into the Ap + gene which codes for this enzyme. The recombinant DNA molecules were purified from the individual clones, subjected to the action of Pst I, and electrophoresed. This allowed the sizing and isolation of the cloned mycoplasmal inserts.

Acknowledgements

I wish to thank the Air Force Systems Command and the Air Force Office of Scientific Research for sponsorship of this research. Universal Energy Systems must be mentioned for their concern and help to me in all administrative and directional aspects of this program.

My experience was rewarding and enriching because of many different influences. Ferne K. McCleskey provided me with support, encouragement, and a truly enjoyable working atmosphere. The help of Sgt Aaron Sinclair, Cliff Miller, and Sgt Joseph Mokry was invaluable in overcomming many technical roadblocks. The concern of Dr Vee E. Davison and William Northam was greatly appreciated. Dr Jerome Schmidt's interest in every phase of this project truly served as a source of stimulation. The encouragement and help of Dr Louis Blouse clearly added to every aspect of this research project.

I. INTRODUCTION:

Mycoplasma hominis and Ureaplasma urealyticium have been implicated as being associated with or the causative agent of many urogenital conditions, infertility, pregnancy wastage, and reproductive failures. They may be responsible for congenital malfunctions of infants.

The Microbiology Section of the Epidemiology Division of the USAF School of Aerospace Medicine at Brooks Air Force Base is particularly concerned with mycoplasma infection of the urogental tract. The term mycoplasma is used commonly to indicate the Class Mollicutes. Special attention is directed at pregnant women in the last two months of pregnancy since these microorganisms can affect the pregnancy as well as the fetus itself. Therefore, a sensitive means of diagnosis would be of great use in screening and testing for mycoplasma infection.

My research inte ests have been in the area of application of a variety of immunochemical and/or electrophoretic techniques in the investigation of structure and function of various proteins, nucleic acids, enzymes, and viruses. My work on the nucleic acid content of the virus particles of Agaricus bisporus, cloning of DNA which is complementary to the virus particles genomic RNA into E. coli, and the development of a biotinylated diagnostic probe contributed to my assignment to the Virology Function of the Microbiology Division.

II. OBJECTIVES OF THE RESEARCH EFFORT:

Currently, there is no method of direct identification of these organisms in clinical specimens. Assessment of samples is accomplished by the isolation and indirect identification of these species on two different culture media. This system has many disadvantages such as the need to purchase two highly complex culture media which are relatively expensive, and the slow growth rate of these organisms demands relatively long incubation periods which greatly delays the assessment of the clinical samples. Thus, the present method of detecting the presence of mycoplasma in clinical specimens is complex, expensive, tedious, and not very exact.

My assignment as a participant in the 1985 Summer Faculty Research Program (SFRP) was to determine if the commercially available Mycoplasma TC Kit marketed by Gen. Probe, San Degio, CA. 92123, could be used for direct examination of clinical specimens. It was determined that the DNA probe, which was the salient ingredient of the kit, contained sequential homology with DNA from a wide spectrum of microorganisms. Thus, the kit was not specific enough to be of any use in the diagnosis of clinical specimens.

Since the Mycoplasma TC Kit could not be utilized, it was decided that an investigation into the development of more specific DNA probes for _M. hominis_ and _U. urealyticum_ should be undertaken during the latter portion of my SFRP and to continue at my laboratory with funding from the Mini Grant Program.

During my 1985 SFRP several important data were collected. The exact conditions for cultivation of the two organisms were determined. Precise DNA isolation protocols were devised and sufficient amounts of DNA were isolated to perform agarose gel electrophoresis of these molecules.

Research in this project resumed at the University of Scranton during January of this year under the sponsorship of an AFOSR Mini Grant. The following had been accomplished prior to the 1986 SFRP at Brooks Air Force Base. Preparation DNA isolation are now routinely performed. The Mycoplasma and Uresplasma genomic DNAs' have been digested with several restriction endonucleases and the fragments observed upon agarose gel electrophoresis.

III.

a. The restriction endonuclease Pst I is of special interest for it generates a manageable number of fragments and has a unique recognition site on the vector DNA pBR322. This recognition (or digestion) site is located within the gene which causes the production of B-lactamase. B-lactamase confers ampicillin resistance. Thus E. coli cells which contain normal pBR322 will be ampicillin-resistant (amp+) whereas those which contain Pst I-generated mycoplasma DNA-pBR322 recombinent molecules will be ampicillin sensitive (amp-). This phenomenon is commonly known as insertion inactivation. Scoring for E. coli cells containing non recombinant pBR322 (amp+) is facililated by the use of Ampscreen discs. These commercially available discs are saturated with a chromogenic substrate which turns yellow in the presence of B-lactamase and remain

blue in the absence of this enzyme. Since pBR322 also contains the gene for tetracycline resistant (tet+), this gene is not affected by Pst I; E. coli cells which contain no pBR322 can be eleminated from any system simply by growing the bacteria in the presence of this antibiotic.

b. With this in mind the following has been accomplished. Mycoplasmal and ureaplasmal DNA has been digested into restriction fragments by Pst I. These fragments contain "sticky ends" which will compliment those on dephosphorylated Pst I. Since this plasmid is lacking its terminal phosphate groups it cannot recircularize upon ligation. If the phosphate group is supplied by a mycoplasmal or ureaplasmal restriction fragment, then a closed circle will be formed on ligation. Thus when the restriction fragments were combined with the pBR322 and ligation was allowed to proceed via the action of T4 DNA ligase, virtually only recombinant DNA molecules were formed.

The recombinant DNA molecules which is a closed circle consisting of a mycoplasma or ureaplasmal DNA inserted into the Amp gene of pBR322. This DNA was then used to transform E. coli HB5 competent cells. One hundred and ten clones which contain mycoplasmal inserts and 49 of E. coli containing ureaplasmal DNA segments have been engineered to date. These clones were isolated on Luria broth which contained tetracycline.

The recombinant DNA molecules were isolated from E. coli by the method utilized by Birnboim (1983). These molecules were electrophoresed on 0.8% agarose gels, and a considerable size variation in the different DNA

molecules was observed. These molecules were further detailed by splicing those molecules with Pst I and subjecting the digestion products to electrophoresis in a 4% gel made from agarose specifically prepared for the examination of small molecular weight fragments. The pore size of this gel will allow only molecules from 50 to 1000 basepairs to enter the gel bed. Thus the linear pBR322 was not seen but the inserts were and they could be sized. The inserts were seen to range in size from 70 to 700 bp. This agrees with the size range which pBR322 can accomodate during its functioning as a vector. More importantly, this size range offers the potential for arriving at an ideal diagnostic probe.

IV. RECOMMENDATIONS:

a. The cloning of mycoplasmal chromosomal segments into E. coli now affords an unlimited inexpensive source of potential DNA probes. However, before these recombinant molecules can be used as diagnostic tools they must be labeled with some type of signal compound so that quantitative and qualitative identification can be accomplished on clinical specimens, the specificity range of the various inserts must be defined, the exact conditions for testing clinical samples determined, and the resulting diagnostic kit must be field tested.

b. The recombinant DNA molecules will be extracted from E. coli by the method of Birnboim and Doly (1979) and Birnboim (1983). These molecules will be further purified by electrophoresis in 0.8% agarose gels followed by elution out of the gel bed onto DEAE anion exchange resin by the

Kontes D-Gel Electrophoresis System. The recombinant nucleic acid will then be subsequently eluted from the DEAE anion bed with 1M NaCl, followed by ethanol precipitation and suspension into an appropriate storage buffer.

Since the pBR322 portion of the recombinant DNA may cause false positive readings in clinical specimens due to the presence of the plasmid in microorganisms (Ambinder, 1986), the normal pBR322 will be utilized as a control in all subsequent tests. Mycoplasmal inserts will be excised from the recombinant DNA molecules and tested for their ability to serve as a probe. If these prove to be too small to visualize, the isolated insert can be attached to a double-standard DNA molecule which will not cross-react with microorganisms which may be present in clinical samples. This increased molecular weight will allow more signal molecules to be placed on the probe and thus permit greater sensitivity.

The probe DNA will be labeled with biotin-11-UTP according to the method of Langer (1981). This labeled probe will be utilized to detect target mycoplasmal DNA which is immobilized on nitrocellulose membranes (Leary, 1983). Probe-target DNA hybrids will be visualized with streptavidin-akaline phosphatase complex. Streptavidin has a tremendous affinity for biotin. The colorimetric reaction produced by the akaline phosphatase of this complex will allow the detection of as little as 0.25pg of target DNA.

c. The cloned genes can be used for purposes other than the probing of target DNA. These genes can easily be sequenced by the method of Sanger (1977). Isolated inserts can be placed into expression vectors such as the pUC series. These vectors allow the translation and transcription of the inserted genetic information. Such a technique can allow for the isolation of the urease gene from Ureaplasma. Cell membrane protein can also be isolated by a similar method.

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Leary, J.J., D.J. Brigati, and D.C. Ward. Rapid and Sensitive Colorimetric Method for Visualizing Biotin-labeled DNA Probes Hybridized to DNA or RNA Immobilized on Nitrocellulose: Bio-blots. Proc. Nat,l. Acid. Sci. 1983, Vol. 80, pp. 4045-9.

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TO: Summer Fellows on the
College Science and Engineering Program (CSEP)

Dear Colleague:

As indicated in your information package and your appointment conditions, UES requests your evaluation of this program.

At the completion of your summer work, please take a few minutes to complete this survey. It is part of the contract requirements and, as your summer appointment period will soon be over, we welcome your impression.

Please return promptly to:

UNIVERSAL ENERGY SYSTEMS, INC.
CSEP Office
4401 Dayton-Xenia Road
Dayton, Ohio 45432

We hope you have enjoyed your summer work.

Sincerely,

UNIVERSAL ENERGY SYSTEMS, INC.

Susan K. Espy
Program Administrator

SKE/mt
1857s

1988 USAF/UES COLLEGE SCIENCE AND ENGINEERING PROGRAM
EVALUATION QUESTIONNAIRE
(TO BE COMPLETED BY STUDENT PARTICIPANT)

Name______________________________ Title______________________

Dept. (at home)____________________ Home Institution__________________

Research Colleague(s)____

Laboratory Address of Colleague(s)__________________________________

Brief Title of Research Topic_______________________________________

A. TECHNICAL ASPECTS

1. Was the offer of research assignment within your field of competency and/or interest? YES_____NO_____.

2. Was the work challenging? YES_____NO_____. If no, what would have make it so?____
____

3. Were your relations with your research colleague satisfactory from a technical point of view? YES________NO________If no, why?____
____

4. Suggestions for improvement of relationship(s).__________________
____
____

5. Considering the circumstances of a summer program, were you afforded adequate facilities and support? YES_____NO_____. If no, what did you need and why was it not provided?_______________________
____

6. Considering the calendar "window" of eleven weeks being limited by varying college and university schedules, please comment on the program length. Did you accomplish: more than_____, less than_____, about what you expected_____?

7. Were you asked to present seminars on your work and/or your basic expertise? YES______NO______. Please list number, dates, approximate attendance, length of seminars, title of presentations (use reverse side if necessary).

8. Were you asked to participate in regular meetings in your laboratory? YES______NO______. If yes, approximately how often?________
____

9. Other comments concerning any "extra" activities.________________
____
____

10. On a scale of A to D, how would you rate this program? (A high, D low)

Technically challenging	A	B	C	D
Future research opportunity	A	B	C	D
Professional association	A	B	C	D
Enhancement of my academic qualifications	A	B	C	D
Enhancement of my research qualifications	A	B	C	D
Overall value	A	B	C	D

B. ADMINISTRATIVE ASPECTS

1. How did you first hear of this program?________________________
____

2. What aspect of the program was the most decisive in causing you to apply?________________________________
____

3. How do you rate the stipend level? Meager______Adequate_____ Generous_______.

4. Please give information on housing: Did you reside in VOQ______, apartment_______, other (specify)______? Name and address of apartment complex and manager's name.____
____

5. Would you encourage or discourage expansion of the Program?
______________________________Why?______________________________
____

6. Considering the many-faceted aspects of administration of a program of this magnitude, how do you rate the overall conduct of this program? Poor______Fair______Good______Excellent______. Please add any additional comments.____
____

7. Please comment on what, in your opinion, are:

a. Strong points of the program:______________________________
____
____

b. Weak points of the program:______________________________
____
____

8. On balance, do you feel this has been a fruitful, worthwhile, constructive experience? YES______NO______.

9. Other remarks:____
____
____
____
____
____
____

THANK YOU

1857s

1988 USAF/UES COLLEGE SCIENCE AND ENGINEERING PROGRAM
EVALUATION QUESTIONNAIRE
(TO BE COMPLETED BY STUDENT PARTICIPANT)

A. TECHNICAL ASPECTS

1. Was the offer of research assignment within your field of competency and/or interest?

YES 21
NO 2

2. Was the work challenging?

YES 20
NO 3

If no, what would have made it so?

There were four of us working on the same project. When something was hard for me, someone else did it. Sometimes one worked while others watched. I didn't feel under pressure to get things done.

Assignment of a longer-term project.

The work was somewhat challenging at the beginning however, once I mastered a subject I did not always have the opportunity to move on to more challenging work.

3. Were your relations with your research colleague satisfactory from a technical point of view?

YES 23
NO

If no, why?

4. Suggestions for improvement of relationship(s).

Possibly better explanations of responsibilities st the mentors feel they won't have to explain every point of a project.

More inter-office conferences & meetings.
Inform mentor of my coming before hand.

I enjoyed favorable relationships with my co-workers and see no need for change.

To work closer on my research goals.

Give the research colleague greater notice of the incoming student.

Collaboration on a project and regularly scheduled meetings with colleague.

I, myself, had the opportunity to meet with Curtiss Selph, my mentor more than once/week. I did not take advantage of this.

More frequent contact would help improve the relationship, as well as more interest in working together.

None, we worked well together.

5. Considering the circumstances of a summer program, were you afforded adequate facilities and support?

YES 22
NO 1

If no, what did you need and why was it not provided?

More help before I flew out here concerning finding living quarters. Help was very good once I arrived (thanks to Wayne Roe).

I would have liked more work to do, because quite often I would have nothing to work on.

6. Considering the calendar "window" of eleven weeks being limited by varying college and university schedules, please comment on the program length. Did you accomplish:

more than 2
less than 7
about what you expected 14

7. Were you asked to present seminars on your work and/or your basic expertise?

YES 5
NO 18

Please list number, dates, approximate attendance, length of seminars, title of presentations (use reverse side if necessary).

a. 2 Aug. 88, 40 people, 10-15 min. talk, ARIES seminar.

b. 17 July 88, 45 min., 30 people, Kinetic Kill Vechicle Nover Interceptor Test. 29 July 88, 20 min., 15 people, KHIT Data Analysis.

c. KHIT Information, 7-22-88, 45 min., 4 presenters, 25 people attended. KHIT Data, 8-4-88, 3hrs, several presenters, 15 people.

d. 7-29-88, about 20 people, 45 minutes, KKV system description. 8-5-88, about 16 people, 30 minutes, ATIP test results.

e. Aug. 5, 88, 25-30 people, which covered the processes involved in making a carbon-carbon structure. This presentation lasted approx. 10 min.

8. Were you asked to participate in regular meetings in your laboratory?

YES 14
NO 8

If yes, approximately how often?

Once a week.

About once a month.

Every other week.

Once every two weeks.

Occasionally once every few weeks.

Once in 8 weeks.

9. Other comments concerning any "extra" activities.

I appreciated the times when I was able to meet fellow participants in this program.

I was allowed to spend time in the somponents laboratory where I was shown the winding process of fiber - composites.

The tours were a very good idea but should have come sooner in the program. The seminars from the various areas were also very good.

The B-B-Q near the conclusion of the UES high school apprenticeship program was quite enjoyable. The tours were enlightening, but lengthy.

Spectator in a rocket motor test firing.

The tours Dick Clark set up were extremely well-planned and worthwhile.

Tours of the main base, Astronautics Laboratory, and NASA Dryder were very interesting.

I enjoyed being asked to attend presentations by contractors.

Dick Clark did an excellent job organizing seminars and tours.

I benefitted immensely from informative tours of EAFB.

I was invited to and participated in presentations to my branch by several contractors.

I enjoyed the AFAL tour and the Edwards Main Base tour.

Tours and seminars, arranged by Richard Clark, were informative and interesting.

I thought that too many activities were planned. I didn't have time for all of them.

I enjoyed the seminars and tours offered throughout the summer. I learned a lot from them.

I really enjoyed the trip to main base.

We had a few going-away lunches for people at work. It brought the people closer.

10. On a scale of A to D, how would you rate this program? (A high, D low)

	A	B	C	D
Technically challenging	9	11	3	
Future research opportunity	10	10	2	1
Professional association	12	11		
Enhancement of my academic qualifications	9	11	3	
Enhancement of my research qualifications	12	7	3	1
Overall value	13	8	2	

B. ADMINISTRATIVE ASPECTS

1. How did you first hear of this program?

Teacher

UES sent me a letter stating that they had intentions of offering me a job.

I was contacted by Chris Gazze, who thought I had been offered a job and wanted to share an apartment. The first I had heard of this program was through another summer fellow.

Through an engineering friend.

I heard about it from Wayne Roe.

I was contacted by the AFAL.

A friend participated last year and this year.

I received an information packet from UES. My name was received by them from Col. Presely with whom I had a co-op interview.

Through UES's application packet.

Received a letter from UES.

From Lt. Col. Homer Presley in regards to my co-op opportunity at the AFAL.

Through High School Apprenticeship Program.

The people from AFAL who interviewed me for a co-op job told me about UES.

When UES contacted me. First heard of lab through Dr. Clark Hawk.

Phone call the last day of my freshman year at Purdue University.

Inquired at EAFB/AFAL concerning summer programs for students.

My Air Force contact was apprised of the program at AFAL.

Though Ann Krach and Thomas Elkins.

Through AFAL contacts.

I heard of it through my boss.

I was contacted by the people in the components lab, where I worked the previous summer.

From Wayne Roe, as I had participated in the UES HSAP.

From a friend at the AFAL.

2. What aspect of the program was the most decisive in causing you to apply?

The time I spent at the Astronautics Laboratory last summer under the high school program was an opportunity that I wanted again.

I liked the opportunity to work at the Air Force Astronautics Laboratory.

Having lived in the area most of my life, the labs excellent technical reputation attracted me.

It was related to my field of study and interest in school.

Technically oriented experience.

The opportunity to experience an aero-space related environment.

The timing of the work period was convenient, and the opportunity for engineering-related work was welcome.

Experience too be gained.

The chance to work at the lab until the AFAL hiring freeze was lifted.

Prior association in High School Program. It was a good experience.

The qualifications and capabilites of the research location.

Originally applied for job through Air Force so question not applicable.

That one of the goals of the program was to create a continued interest in engineering with the student.

Research related to my career goals/opportunities and primility to home (permanent residence).

The ability to work in Nuclear Propulsion (subject) at the AFAL (location).

The ability to participate in the Astrnautics program.

Location.

I would have been hired anyway (under a different contract) for $5 an hour. So I guess it was the salary.

The experience I would gain.

Great opportunity for summer work in my future career field.

The experience.

3. How do you rate the stipend level?

Meager	3
Adequate	18
Generous	2

4. Please give information on housing:

Did you reside in:

VOQ	
apartment	10
other (specify)	13

Name and address of apartment complex and manager's name

5. Would you encourage or discourage expansion of the Program?

Encourage	18
Discourage	5

Why? Encouage

Super career enhancement opportunity.

It was a good opportunity to work with scientist and engineers in fields of interest during college. It gives us an advantage over our fellow students.

This was an excellent experience and I am told the students results were beneficial.

It gives people studying science or engineering in school to apply some of the things they learned in school and decide if this is what they really want to do.

The program is an excellent opportunity for students to get experience and for the Air Force to get work done cheaply.

The program allows students who are not co-op's the opportunity to experience the aero-space field.

It's got potential.

It gives one the chance to be challenged at one of the foremost labs in the country.

It is great exposure for science/engineering students.

It gave beginning engineers a good opportunity to gain hands on experience.

It gives students some idea of what to expect after graduation and experience similar to a co-op job.

Gives invaluable experience to the student working his way through school.

The program is a beneficial learning experience and more students may profit from it.

Other places (such as Edwards AFB) could profit at least as much from this type of program.

Because it is excellent advertisement to recruit future employees at AFAL.

The program has potential, however more should be done in the planning of what a student will be working on.

Because it is invaluable to students who wich to gain experience in their scientific field.

I think AFAL really likes having summer hires around.

It helped me to get away from the "text-books" theory.

Why? Discouage

Because of lack of organization, I feel the program already involved too many people.

The program seems too large to handle already.

There are already too many students here for the amount of work available.

I feel that the number of people given positions at the AFAL was adequate.

6. Considering the many-faceted aspects of administration of a program of this magnitude, how do you rate the overall conduct of this program?

Poor	
Fair	8
Good	14
Excellent	1

Please add any additional comments.

In the summer of 1987, I worked for Universal Energy Systems on the high school program. Working as an employee of the company made it easier to concentrate on my work, because I was not trying to figure out the administrative paperwork.

I feel the system was a good idea, but organization of the program was not very good. My focal point coordinator was on vacation when several of us were scheduled to arrive.

Having Dick Clark out at the laboratory was immensely helpful.

The mailing of the applications sooner would helped the program. Also the paychecks need to be sent sooner than they were.

Mailing applications, appointment letters, and pay chaecks in a more timely manner would greatly boost morale among the CSEP participants.

Slow delivery of pay checks (received about 3-4 weeks after bill was sent).

The greatest problem with the administration was the initial contact.

Not notified until after program started that I was envolved.

Late start but afterwards conducted fairly well.

The applications came out quite late but other than that the administration has been excellent.

My rating would have been higher, had we not been considered self-employed.

The procedure of obtaining badges should have been smoothed out also, paychecks did not arrive as fast as possible.

7. Please comment on what, in your opinion, are:

a. Strong points of the program:

The people at the Astronautics Laboratory who I worked with taught me a lot. When, I phoned UES in Dayotn, they seemed helpful. Having a coordinator on site was nice.

The experience and opportunities to work with researchers of the Astronautics Laboratory closely.

I feel that I learned quite a lot about "real workd engineering" and the field of composite material.

The chance for students to do some career exploration during the summer.

The opportunity for college students to apply their skills and knowledge during the summer time.

Gained valuable computer skills, location of program.

It provides undergraduates an opportunity to gain engineering-related experiences and it is located in California.

Many tours and educational opportunities were available. The chance to actually gain engineering experience was provided.

Wroking in actual research areas.

The areas and projects we were allowed to work with, the location, and the people we worked with.

Experience was good and I was challenged. Tours & seminars were well done.

All of the different opportunities that the student has to take advantage of.

thoroughly administered and directed.

Close affiliation of students with engineers working at the leading edge of propulison technology.

The ability to work with professional engineers and work experience.

The opportunity to be involved in working engineering while enrolled in school.

Useful, on-the-job experience. Nice salary.

It is a good opportunity to get exposed to real research situations and ideas.

Great opportunity for younger undergraduates to have experience in their career field, and to work with scientist & engineers.

the program gives students lots of independent. We can work on what ever our interest maybe.

b. Weak points of the program:

It would have been nicer if we were employees of the company instead of contractors.

Lack of organization caused a lote start in beginning any actual work. There were many points of the program had been poorly explained to me and caused unnecessary delays.

The only possible weak point would be the ambiquity of the tax situation.

Mailing of paychecks and the organized events, such as tours should have started earlier.

Administrative timing.

Individual contracts, lack of housing information, initial contact.

There wasn't enough work for us to do, but the work was relatively interesting.

Employer was uninformed - poor contact.

The delay in starting the program cost me 4 weeks of possible work/due to college starting back. For the same reason I needed to cram to finish my report.

Time window of program can you please start in May.

Finalizing acceptance of UES people and getting them out here to work.

Housing concerns - I came out here with no clue about what to do in this area. Need more up front info on tax liabilities involved in being a contractor. Distinction in paperwork treatment between faculty & college undergrads, esp. final report format. Late start.

Needs to be better organized in the beginning so everything runs smoother for everybody.

'Independent contractor' status resulted in excessive taxation after pay and little flexability in time-period of program.

Sending disbursment requests to Dayotn, OH for work in Edwards CA.

I finished spring semester May 15 but the UES summer hire program started a month later. I finished my last 2 weeks with school already in session.

Planning.

Too many activities. We were also considered self-employed, which I don't think was fair. As a result, we couldn't write anything off.

The handling of paychecks and badges could have been improved also, it would have been nice to have social security and federal taxes removed from our pay before we received it.

The one thing that I found very disappointing is the time schedule of the program, which seems to be aimed more for universities on the quarter system. USC gets out the first week in May, and I would rather start working in early to mid May than in June. I was only able to work 10 weeks because of my college schedule. It would help tremendously if the starting date were moved up a couple weeks.

I would have liked to set-up an occassion where all the UES people can be introduce to each other.

8. On balance, do you feel this has been a fruitful, worthwhile, constructive experience?

YES 23
NO

9. Other remarks:

I had many problems during the early part of the program. Lack of a contact point and almost no organization caused many of the problems. Many of the specifics of the program had not been properly explained - for example, I didn't receive instructions for the final report until very late in the program. I do, however, feel the technical challenges were very rewarding and beneficial . The opportunity and experiences were very worthwhile.

I would like to thank UES for giving me the opportunity to work at the lab this summer. This summer was very enjoyable and given the opportunity, I would glaoly work for UES at the lab next summer.

I really enjoyed my summer and I feel I learned many new things that will be valuable in the future.

Overall, the CSEP was enriching, rewarding, and enjoyable. I am glad to have participated.

I called the stipend rate 'meager' because of the fact that we are "self-employed contractors" which made the normally adequate pay-scale unattractive after social-security and other taxes.

I'm looking forward to returning as a co-op student in January.

I was fortunate to get into a project that kept me busy & stimulated my interest as well, however, I know some students weren't so fortunate and often were bored at work. It seems to me that in a program of this nature, the programs that the students are going to be involved in should be analyzed prior to the student working on it. In this way, students would be assured of staying busy and having a greater sense of accomplishment after each day of work.

I am an out-of-state student who school (Yale University) is on a different schedule than California public schools. I am on a semester system and complete my spring term in early-mid May. The program was not flexible enough to permit me to start working before June 20th. Since I had to return to college by the 1st week of September, I missed the opportunity to work the full - 11 weeks of the program.

RESEARCH REPORTS

1988 COLLEGE SCIENCE AND ENGINEERING PROGRAM

Technical Report Number	Title	Student
1	The Liquid Droplet Radiator	Charla Beckman
2	Computer Programs in Theoretical Chemistry	Kenneth Chew
3	Development and Structure of a Kinetic Energy Weapon System	Cade Coombs
4	Thermonuclear Reaction Bibliography, with Cross Section Data Examination of Four Promising Advanced Reactions	Larry Cox
5	Utility Programming to Support Data Analysis	Johnson Earls
6	PATRAN Finite Element Analyses	Christopher Gazze
7	Insulation Combustion and Artificial Intelligence Expert Systems	Gregory Hall
8	Mode One Interlaminar Fracture of 2-D Carbon-Carbon	Bruce Hinds
9	Development of Solid Performance Program and Expert System Analysis	Anjanette Knappenberger
10	An Interactive Frequency Analysis Program for Time Series	Liron Kronzon
11	Nuclear Propulsion Modeling	Andrew Martin
12	Creating a Preprocessor and Editor for Astronautics Lab's ISP Program	Francis McDougall

13	Regenative Cooling Limits of N2O4 & MMH for Upper Storable Rocket Engines	Bruce Pham
14	Rocket Nozzle Geometry	Judith Pletsch
15	Computer Aided Composite Design and Embedded Sensors	Gregory Price
16	Fabrication and Processing of Carbon-Carbon Structures	Janet Reust
17	Chemical Vapor Deposition (CVD) on Carbonaceous Materials	Melissa Rose
18	Data Analysis and Manipulation for the Kinetic Kill Vehicle Hover Interceptor Test	Natalie Stubbings
19	Integrated Test Facility Activation for Hover Testing Kinetic Kill Vehicles	Edward Tomlinson
20	Summer Work Effort	Simon Turner
21	Mechanism of Chemical Vapor Deposition (CVD) on Carbons	Tamara Vass
22	Damping of Large Space Structures	Marie Webb
23	Solid Rocket Motor Data Base	Brad Yost
24	Summer Work Effort	Christopher Zarobsky

FINAL REPORTS

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

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Conducted by the

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FINAL REPORT

THE LIQUID DROPLET RADIATOR

Prepared by:	Charla M. Beckman
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Research Location:	AFAL/VSSP Edwards AFB, CA 93523-5000
USAF Researcher:	Michael Powell
Date:	1 Sept 88
Contract No:	F49620-88-C-0053

THE LIQUID DROPLET RADIATOR

by

Charla M. Beckman

ABSTRACT

The Liquid Droplet Radiator (LDR) was designed to provide thermal management for high powered space vehicles with a relatively low, in comparison to other types of thermal management, system mass. Tiny high temperatures droplets are shot from an injector towards a collector. As they move towards the collector this heat is radiated to space. By the time the droplets reach the collector, they have cooled and are collected to be recirculated through the LDR system. A computer code for the LDR was used to make predictions of weights and design concepts based on the choice of fluid, the power level, and the temperature. Also, a liquid rocket engine injector was obtained and modified in order to perform tests that would be used in the development of a collector for the LDR.

Acknowledgements

I would like to thank the Air Force Systems Command and the Air Force Office of Scientific Research for sponsoring the College Science and Engineering Program. Thanks also go to Universal Energy Systems for making this summer possible. I would also like to thank all the people at the Air Force Astronautics Laboratory who made my time there an enjoyable learning experience.

I would especially like to thank my mentor, Mike Powell, for the chance to work on such a fascinating project. I also appreciate the help given by Capt. Alex Webster and Lt. Eric Kouba.

I. INTRODUCTION

In the future, thermal management will play an increasingly more significant role in space technology. There are plans for a space station, a moon base, and even a trip to Mars. All of these require enormous amounts of power and with this need for increasing amounts of power, the necessity of some kind of thermal management becomes an issue that cannot be ignored. The Liquid Droplet Radiator (LDR) is one of the methods that has been proposed and is now being investigated as a means of providing this necessary operation.

At the University of California at San Diego, I am studying engineering. My interests lie towards mechanical engineering and this job was one that would provide me with some experience in the field. For this reason, the mentor I was assigned to was a mechanical engineer. At this time he is working on thermal management in space vehicles and for that reason I had the opportunity to work with him on the LDR. This summer gave me the chance to learn what it means to be a mechanical engineer.

II. OBJECTIVES

The LDR system is one that can operate at different temperatures and powers based on the type of fluid chosen. The choice of fluid would depend on the kind of temperatures the power source produced. For this, it is important to know the particular characteristics of the working fluid chosen for the LDR. This was done through the use of a computer code designed specifically for this purpose.

A LDR injector was needed for the contractors who are in the process of developing a collector for the LDR and required the ability to create the same droplet density environment as that found in the LDR. Cold flow tests and calculations needed to be made to discover the characteristics of the injector and whether or not the contractor would be able to adapt this injector to their own facilities where they could use it to carry out tests on their collector. They are only able to operate at very low flow rates and this is to be taken into consideration.

This summer, it was my responsibility to use the LDR computer code to run all the required cases and graph them in order to find the temperature optimization. The calculations for the model LDR were also my responsibility and done under the guidance of my mentor.

III.

The LDR (Fig.1) consists of four major parts: an injector which produces the liquid streams, the liquid streams which radiate the rejected heat, the collector that catches the liquid streams and recirculates them for reuse, and the system piping. A system design code was created to design these components for the LDR and to describe the conditions under which they will operate. At the beginning of the program the user is asked to enter the power of the system, the inlet and outlet temperatures, and the fluid that will be used. If no values are entered, there are a set of default values that are used. The code operates by going through a series of iterations in order to optimize on numbers entered by the user and in this way gives a fairly accurate estimate of what the system and fluid masses are while giving estimates for structure sizes and design. All the newly computed data is placed into an output file. This process can be done in a few minutes or a few hours depending on how close the data is to optimization.

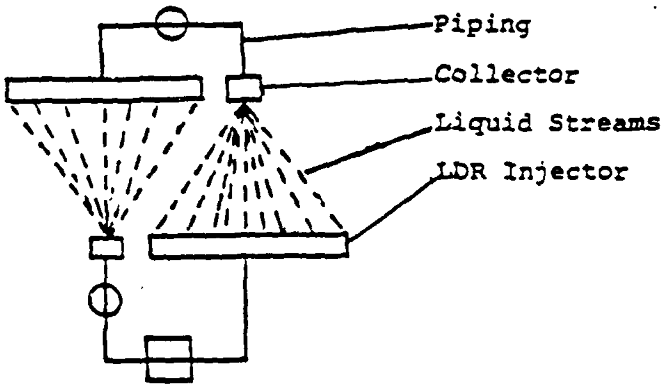

Fig. 1: The Liquid Droplet Radiator.

In order to find the temperature optimization of the LDR working fluids it was necessary to run several cases using the LDR system code. To do this, the power level and working fluid were kept constant while the inlet temperature was varied. These points points were then graphed (Fig.2) to find the temperature optimization of the particular working fluid.

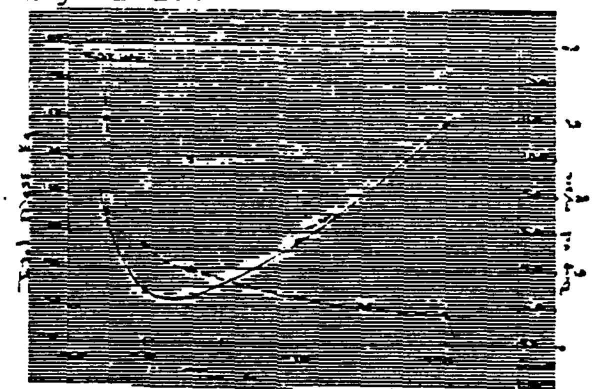

Fig. 2: Optimization of LDR for Lithium at 50kwt.

To make the LDR injector, a device was needed that would produce droplets of approximately the same size as those used in an actual LDR. A liquid propellant rocket engine injector was found but had not been cleaned the last time it was tested and many of the orifices were plugged. All types of methods were used to clean it, including back flushing many times, but a few of the orifices remained plugged. After the injector was cleaned, the outer orifices were plugged using epoxy because they did not have a matching orifice and would not be used in the test. The injector was fitted with a valve that enabled the momentum of the two circuits to be balanced which would create a straight stream of water from the injector. This also made

it possible for both circuits to be tested independently; if any of the orifices on that circuit were blocked then it and its matching orifice on the other circuit was also blocked so as to prevent any distortion by stray liquid jets. If the streams were distorted, it may cause a loss of fluid which may lead to a weight penalty because of the need for extra fluid to make up for the loss.

When all the necessary orifices were plugged, demineralized water was flowed through the injector at various pressures. The flow rates at each of these pressures was recorded for both the fuel circuit and the oxidizer circuit. When these points were graphed (Fig.3), a prediction could be made about the contractors ability to use the injector with adequate results.

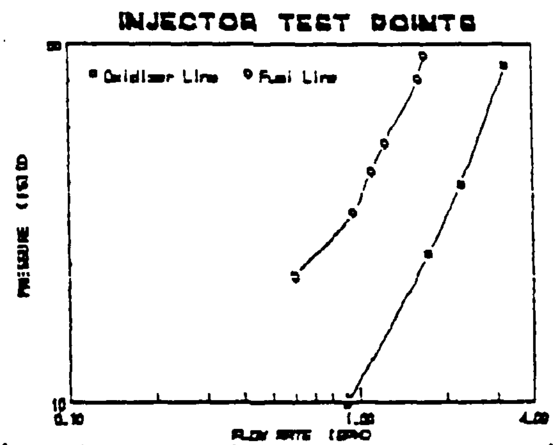

Fig. 3: Graph of the test points

After this task was completed , many other calculations were needed, including a correction factor for changing the fluid from demineralized water to to Dow Corning 705 fluid. The velocity, droplet diameter, and the affective area were also necessary calculations.

IV.

The first calculations were done in order to find the affective area of the jets from the injector used in the tests. This was done using numbers taken from the graph of the test points:

$$A_{CD} = \frac{\dot{\omega}}{\sqrt{2g\rho\Delta P}} \tag{1}$$

where $\dot{\omega}$ is the flow rate (kg/sec), g is the force of gravity (m/sec^2), ρ is the density of the fluid (kg/m^3), and P is the drop in pressure (kg/m^2).

After the affective area was calculated, the test point graphs were then converted to Dow Corning 705, the fluid that the contractors would be using. In order to do this the Reynold's number had to be found. Using the standard equation (Baumeister, 1958) for finding the Reynold's number the following formula was easily derived:

$$R_n = \frac{.0132\,\dot{\omega}}{\mu\sqrt{A_{eff}}} \tag{2}$$

where 0.0132 is a constant and μ is the surface tension (N/m). By using the fluid density of both water and Dow Corning 705, the Reynold's numbers for both were found. The flow coefficients were then determined using these numbers and were used to find the Δ P (Howell and Weathers, 1970) of the Dow Corning 705:

$$\Delta P_{DC} = \left(\frac{K_{F_{H_2O}}}{K_{F_{DC}}}\right)^2 \left(\frac{\rho_{DC}}{\rho_{H_2O}}\right) \Delta P_{H_2O} \tag{3}$$

where K_F is the dimensionless flow coefficient for Dow

Corning 705 and water, and ρ is the density (kg/m^3) of each, respectively. From this a new chart (Fig.2) was made using the ΔP_{DC} versus the flow rate. From this, it was determined that the injector would work for the contractor as it was shown to work at their low flow rate.

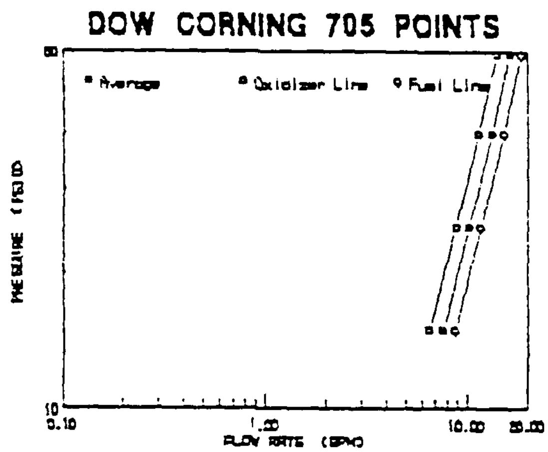

Fig. 4: Graph of the Dow Corning 705 corrected curves.

Once the curves were converted for Dow Corning 705, it was then simple to calculate the velocity. The jet velocity was calculated using:

$$V = K_F \sqrt{\frac{2g \Delta P}{\mu}} \tag{4}$$

The velocity of both the fuel circuit and the oxidizer circuit were found using this equation (Baumeister, 1958).

The jet diameters were measured and from this an average droplet size was found (Fig.5). Two different equations (Schuman and Beshore, 1978) had to be used because of the differences in jet diameter of the fuel line

and that of the oxidizer line:

$$\overline{D}_1 = 2.91\times10^{4}\, V_1^{-.76}\, d_1^{.79}\left(\frac{d_2}{d_1}\right)^{.023}\left(\frac{\rho_1 V_1^2}{\rho_2 V_2^2}\right)^{.165}\left(\frac{\sigma_1}{\rho_1 d_1 V_1^2}\right)^{.18} e^{.00357\left(\frac{\mu_1 V_1}{\sigma_1}\right)} \tag{5}$$

$$\overline{D}_2 = 2.72\times10^{4}\, V_2^{-.57}\, d_2^{.65}\left(\frac{d_2}{d_1}\right)^{-.17}\left(\frac{\rho_1 V_1^2}{\rho_2 V_2^2}\right)^{-.25}\left(\frac{\sigma_2}{\rho_2 d_2 V_2^2}\right)^{.18} e^{.00357\left(\frac{\mu_2 V_2}{\sigma_2}\right)} \tag{6}$$

$d_1 < d_2$

where 2.91×10^4 and 2.72×10^4 are conversion factors and σ is the surface tension (N-sec/m^2). These numbers were then used to determine the range of droplet size distribution.

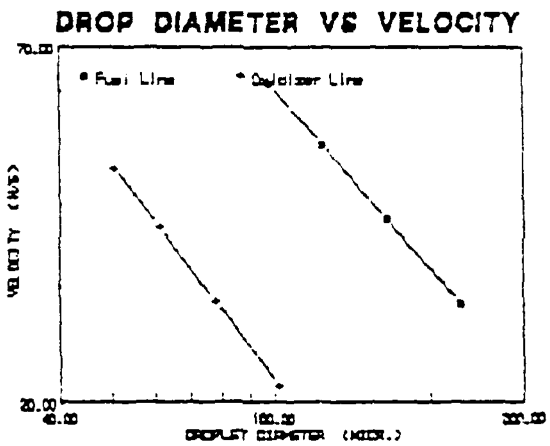

Fig. 5: Graph of droplet diameter vs. velocity.

V. RECOMMENDATIONS

In conclusion, I recommend that studies on the LDR continue. There are many things that look promising, including the low mass of the system, that would benefit from further study. The results of the studies done so far and the importance of thermal management to space technology warrants further and more intensive research.

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1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

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FINAL REPORT

Computer Programs in Theoretical Chemistry

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Date: 06 Sep 88

Contract No: F49620-88-C-0053

Computer Programs in Theoretical Chemistry

by

Kenneth S.J. Chew

ABSTRACT

Three computer programs were developed or adapted for use in theoretical chemical research. An auto-formatting text editor called ISPEAK was developed to facilitate the fast and easy creation and editing of input files for the Air Force Astronautics Laboratory Theoretical Isp program. ISPEAK is an original program. VAX-based versions of Potfit and AtmBis were adapted from the IBM mainframe-based source codes. Potfit is used to calculate dissociation energies of diatomics, and AtmBis is used to calculate polarizabilities of atoms, and special line-parsing routines were developed for input for this program. All three programs were tested and found to work well.

I. INTRODUCTION:

Computational methods are an indispensible part of research in theoretical chemistry. To obtain an acceptable degree of accuracy, numerous iterations of very involved calculations must be used. This is the specialty of contemporary computers, and computers are thus extensively used in theoretical chemical research.

Unfortunately, most of the available scientific computer programs were written for relatively old computer systems. They typically use outdated methods of input and output, and many such programs do not explain what input is expected or have very rigid rules for input. The output often has a cumbersome format or uses peculiar units. To adapt these programs for use with different computer systems, they must be modified or augmented.

My training and experience provided the qualifications necessary for this kind of computer work. I have several years of computer programming experience including work on micro- computers and VAX "super-minicomputers". My formal programming training includes Pascal, BASIC, and assembly language for the 8088, 8080, and 6502 microprocessors. I have also worked with FORTRAN and LISP. Prior to the work described in this report, I had two summers of experience in programming for scientific applications, including one summer with the ARIES group, with whom I am working this summer. In addition to my computer experience, the classes I have taken in Chemistry, Physics, and Materials Science contributed to my assignment to the ARIES group.

II. OBJECTIVES OF THE RESEARCH EFFORT:

At the Air Force Astronautics Laboratory (AFAL) in Edwards Air Force Base, the ARIES (Applied Research In Energy Storage) group uses a myriad of computer programs to facilitate research in highly energetic fuels and fuel additives. Among the topics investigated are the specific impulse (Isp) of fuels, the dissociation energies of atoms, and the polarizabilities of atoms. Unfortunately, the AFAL Theoretical Isp program requires strict input formatting. Furthermore, there were no suitable programs which could be used in original form at the AFAL to calculate dissociation energies of diatomics or polarizabilities of atoms. A good deal of computer work would be needed to solve these problems.

My assignment as a participant in the 1988 College Science and Engineering Program (CSEP) was to provide computer support in theoretical chemical research for the ARIES group. There are many areas in which computer support would be welcome, but the brevity of the CSEP limited the scope of my efforts. It was decided that my research efforts would be divided among three different projects: easy input to the Isp program, cubic spline and curve fitting routines to determine dissociation energy, and adaptation of a polarizability calculating program.

Input to the AFAL Isp program consists of opcodes and data for the opcodes. There are nearly sixty possible opcodes, and each of them requires a specific data format. Because of the number of different formats and the use of right and left justification for the different fields within a data line, most text processors cannot provide a fast or convenient method for editing input files for the AFAL Isp program. The source code for the program was not readily available, and rewriting programs is highly error prone. For my first project, I was to create a program to facilitate the fast and easy editing of input files for the AFAL Isp program.

The attractive and repulsive forces between two atoms which vary with internuclear separation are of great interest to the ARIES group. The dissociation energy of a diatomic molecule can be estimated by minimizing the curve of binding energy versus internuclear separation. For my second project, I was to develop a program which could read in a set of coordinates for a potential energy curve, smooth the curve by using a cubic spline routine to interpolate points between the input coordinates, write the smoothed curve to a file usable by a PC-based plotting program called Sigma Plot (Jandel Scientific Co.), and find the minimum of the curve.

When an atom is placed in an external electric field, the field distorts the electronic distribution of the atom. The polarizability of the atom is a measure of this distortion (McQuarrie, 1983). To obtain an accurate estimate of an atom's polarizability involves intensive calculations. There exists a program to calculate polarizability called AtmBis (pronounced Atom-bice), written by Walt Stevens at the National Bureau of Standards. However, AtmBis was written for an IBM mainframe computer, and there are no IBM mainframes readily accessible to the ARIES group. My third project was to adapt AtmBis for use on the AFAL's VAX computers.

III. ISPEAK:

a) To meet my first research objective, I created a text editor called ISPEAK ("I speak"). Because this was an original program, several design decisions had to be made, especially those concerning data structure, screen display, keyboard input and prompting, and disk input/output. The decisions are explained below.

Data Structure. To provide fast insertion and deletion of lines in the input file, a doubly-linked list data structure was implemented. Each line in the input file is linked to the line before it and the line after it. To change the position of a line, only the links need to be changed. To avoid accidentally overwriting memory locations outside the data segment, the linked list was contained within a static array, and array indices rather than pointers were used as links. The array also included a linked list of empty lines. Lines are moved between the two lists for insertion and deletion. Associated with each line are two links, a string of characters which the user can edit, a field which determines whether the line contains data or an opcode, and a field which determines the format of the string of characters. This data structure was designed to facilitate the fastest possible editing and automatic formatting of data without risk of overwriting memory locations outside the data segment.

Screen Display. An editor should allow the user to observe the input file as he edits it, display pertinent information about the input file, show how to use its main functions, and prompt the user for specific input (like file names) when needed. To accomplish this in an efficient and straight forward manner, ISPEAK's screen display is divided into a number of boxes, each with a unique function.

Input and Prompting. Since formatting is the most time consuming part of editing an Isp input file, I determined that ISPEAK should automatically format input as the user types it in. Prompting occurs in a special box on the screen and is done only when specific input is necessary. Prompting always includes a message explaining what input the program requires.

Disk Files. ISPEAK reads from and saves to standard DOS ASCII files because this format is usable by the AFAL Isp program and by most word processors. Input files created with other editors can thus be easily adapted or used directly with ISPEAK.

b) The results of my efforts and approaches to ISPEAK are embodied in the working progam as described in the following excerpt from the ISPEAK instructions.

Notes.

Escape Commands: These are merely commands which are invoked by a key sequence which starts with the [Escape] key. For example, you can insert a line by pressing [Escape], 'I'.

File Structure: ISPEAK treats your file as a list of lines, and each line is composed of cells. Each cell holds either an opcode or data for an opcode. Each opcode requires a line all to itself, but several data cells may coexist on a line. ISPEAK allows a maximum of 300 lines in a file.

Starting ISPEAK.

ISPEAK can be run like any other executable file.

After a short pause, ISPEAK's startup screen appears. If you have a color display and can comfortably read the 'Test of your display's contrast', press '=' to continue. Otherwise, press 'C' to continue. This will determine the color scheme of ISPEAK's editing screen.

ISPEAK's editing screen is divided into several parts. Note that if you pressed 'C' in the startup screen, the three boxes at the bottom of the editing screen appear as one wide box rather that three smaller boxes. Do not be alarmed: they still function correctly.

* The column index (red on color displays / white on black and white displays) occupies the topmost line of the screen. This is for people who don't yet trust ISPEAK's formatting ability and are obsessed with counting columns.

* The EditBox (blue/black) is the largest area on the screen. This is where the file's contents are displayed. The L)ist codes and show directory routines also use this box to display data.

* The DialogueBox (green/white) occupies the lower left corner of the screen. This is where ISPEAK prompts you for specific input, displays the current contents (called the 'old value') of the current cell, and displays messages. It's a good idea to keep and eye on the DialogueBox.

* The OptionsBox (red/white) is the middle box on the bottom of the screen. The escape commands and some of the cursor movement keys are displayed here. The text in this box does not change. It is meant only to remind you of what options are available and how to invoke them.

* The StatusBox (green/white) resides in the lower right corner of the screen. Here, ISPEAK shows the opcode for which it is currently formatting

data, the current line number, the total number of lines, and the number of the leftmost column of the current cell. There is also a reminder about which escape commands can be canceled by [F1].

The Editing Sequence.

Editing a file is a simple task. It consists mainly of a cycle of three steps.

a) Move the cursor to the desired cell.

b) Edit the cell to your heart's content.

c) Invoke an escape command if necessary.

A) Moving The Cursor.

The cursor is the grey/white rectangle in the EditBox. ISPEAK allows you to move the cursor to any cell within your file. Note that you cannot move the cursor beyond the limits of the file. Thus if your file consists of only one cell, you will need to insert more lines to experience the thrill of extended cursor movement.

The cursor movement keys are based on the numeric keypad (with numlock OFF). They are described below.

The up and down arrow keys move the cursor up or down one line. Note that when you move between lines, the cursor goes to the leftmost cell in the new line. The left and right arrow keys move the cursor left or right one cell.

The [PageUp] and [PageDown] keys move the cursor nine lines up or down (or as close to nine lines as possible).

The [Home] key moves the cursor to the leftmost cell of the current line, and the [End] key moves the cursor to the rightmost cell.

B) Editing A Cell.

When the cursor is placed on a cell, the current value of the cell is shown in the DialogueBox. (ISPEAK calls it the old value.) As you type in a new value for the cell, it is displayed, automatically formatted, inside the cursor. ou can use [Backspace] to delete characters while you are editing a cell. To restore the old value and get rid of the new value, press [F1] before accepting the new value. To accept the new value, press [Enter] or one of the cursor movement keys.

C) Escape Commands.

Escape commands are invoked by pressing [Escape] followed by the first letter of the command name (e.g. [Escape], 'I' to I)nsert; [Escape], 'D' to D)elete). They are described below.

I)nsert (a new line below the current line)

F)ind (an opcode)

L)ist codes. This command will display a list of the ISP opcodes and short descriptions in the EditBox.

R)ead. This command will append a file from disk to the end of the file you have in memory. ISPEAK prompts you for the name of the file you wish to read, and uses the last filename you entered as a default. If you enter a null string instead of a filename, ISPEAK cancels the R)ead command. If you enter 'DIR' instead of a filename, ISPEAK prompts you for the directory you wish to display. It uses the last entered directory as a default.

S)ave. This command works very much like R)ead, except that it copies the file in memory to a file on the disk rather than copying a disk file into memory.

N)o format. When No Format is turned ON, ISPEAK divides your file into cells which are only one character long (thus, there is no formatting within the cells).

Q)uit. If you press [Escape], 'Q', ISPEAK will ask if you really want to quit. ou can leave ISPEAK and lose everything that has not been saved by pressing "; *you can erase your file from memory* (but not from disk) and restart ISPEAK by pressing 'N'; or you can cancel the command and return to your file by pressing [F1]. It is usually a good idea to save your file before you quit.

Block Operations. M)ove, C)opy, and D)elete operate on a user selected block of lines. This block may be as small as one line or as large as your file. To use one of these commands, put the cursor on the first or last line of the block and press [Escape] followed by 'M', 'C', or 'D'. You can use [F1] to cancel a block operation.

IV. <u>POTFIT</u>:

a) Dr. Marcy Rosenkrantz, the research scientist who was most interested in the dissociation energies program I was to develop had the source code for an existing program called Potfit (by Walt Stevens, amended by Dr. Rosenkrantz), which contained a cubic spline routine and several curve fitting routines. Rather than re-inventing the wheel, I adapted Potfit to the needs of the ARIES group. Since Potfit was written for an IBM mainframe and used some custom input routines, all the input statements were changed to read from the system default input device on the VAX. The output was also changed from 132 column format to 80 column format by dividing long title lines and

turning tables sideways and was redirected to the system default output device. As Potfit produces a considerable amount of output and several wide tables, this was quite time consuming. In addition to modifying the input/output routines, routines to find the minimimum of the curve by using the first derivative test and to save the interpolated potential energy curve were developed and implemented.

b) Because Potfit now uses system default input and output devices, it can be run interactively or as a batch job. Running Potfit from a batch job allows the user to perform other tasks while Potfit is executing, and all of Potfit's output is saved to a log file for later viewing. The output fits neatly on an 80 column display for ease of reading.

The new minimization routine is performed before Potfit's Morse fit routine, and the result is used as an initial guess for the Morse fit. This greatly reduces the number of iterations required to produce acceptible results and thus reduces computing time. The VAX version of Potfit was tested and found to produce results comparable to the results from the IBM version.

For a graphic representation of the interpolated potential energy curve, Potfit produces a file called Potfit.out, which contains the coordinates of points along the curve. The user specifies the interval of the coordinates, and Potfit interpolates the values for the coordinates in electron-volts, bohrs, and wavenumbers. The file can easily be transferred from the VAX to an IBM compatible PC for use with such plotting programs as Sigma Plot (see figure 1).

V. ATMBIS:

a) As with Potfit, all input routines in AtmBis had to be replaced by input routines usable on the VAX. For expedience, namelist directed input was used. This allowed me to keep careful track of the values of the input paramters and to devote my time to work out other incompatibilities between the AtmBis source code and VAX Fortran. After the source code was revised so that the VAX version would produce acceptible results, input routines to emulate the input on the IBM version were developed and implemented.

b) The VAX version of AtmBis can be run interactively or from a batch file. Because of the new input routines called GETSTR, FINDI4 and FINDR8, which read in a string

of input and parse it for 4-byte integers and 8-byte real numbers, input files intended for the IBM version are compatible with the VAX version. AtmBis was tested and found to produce results comparable to those produced by the IBM version. Except for processing time, execution and performance of AtmBis is nearly the same for the VAX and IBM mainframe versions.

VI. RECOMMENDATIONS:

a) The ISPEAK source code, executable code, and documentation easily fit on one 360K floppy disk. Already two people outside the ARIES group have used ISPEAK with the ISP program and have given positive feedback. If there is a list of public domain software available at the AFAL, ISPEAK should be submitted to the list and distributed to those who want it.

The source and executable codes for Potfit and Atmbis should be placed in a VAX account which is accesible by all members of the ARIES group. Documentation for these programs is short, and photocopies can be distributed to those who need it. It is strongly suggested that these programs be run as batch jobs since this allows the user to perform other tasks while the programs are executing and saves all output to a log file.

b) To improve ISPEAK's utility and ease of use, routines should be added to delete a disk file and to run the Isp program from within ISPEAK. This would allow the user to edit, view, and submit Isp input files multiple times without exiting ISPEAK.

The input routines for Potfit should be replaced with those developed for AtmBis. This will allow input files for the IBM version to be used with the VAX version. A PC based version of Potfit would allow direct use of Potfit output files with such plotting programs as Sigma Plot and would free the more costly VAX cpu time to be used for other jobs.

AtmBis could be further tailored to the needs of the ARIES group by modifying it to use Gassuian basis functions rather than Slater basis functions. This is possible through the use of a linear combination of Gaussian functions to approximate each Slater function. The Stepit routine could then be used to minimize the square of the difference between each Slater function and its associated linear combination of Gaussian functions.

ACKNOWLEDGEMENTS

I would like to thank the Air Force Systems Command, the Air Force Office of Scientific Research, and the Air Force Astronautics Laboratory for their sponsorship of this research. Universal Energy Systems must be mentioned for their efforts in the coordination and administration of this program. Mr. Wayne Roe and Mr. Richard Clark deserve thanks for their efforts in making the College Science and Engineering program possible and enjoyable.

I would also like to thank the many people in the ARIES group who helped make my experience productive, rewarding, and enriching. I would like to thank Dr. Steve Rodgers for his suggestions for ISPEAK's look and feel and for his help with the administrative aspects of this program. I would like to thank Dr. Marcy Rosenkrantz for all her help and advice with debugging and testing Potfit and AtmBis and for explaining the chemical concepts necessary to understand these two programs. Dr. Phil Christiansen should be thanked for his help with the quirks of the VAX/VMS operating system. Lt. Monte Turner and Lt. Steve Thompson must be mentioned for their interest in my work and assistance in the office. I would like to thank Mrs. Cris Sandstrom for her help with various administrative aspects of this program. Finally, I would like to express my appreciation to all those whom I have not mentioned.

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NOTES

Potfit was written by Walt Stevens with several amendments and extensions by Dr. Marcy Rosenkrantz. This program relies heavily on a routine called Stepit by J.P. Chandler of the Physics department at Indiana University.

AtmBis was written by Walt Stevens at the National Bureau of Standards and is based on the SCF algorithm of the BISON code which was developed by Chris Wahl at Argonne National Laboratory.

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

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UNIVERSAL ENERGY SYSTEMS, INC.

FINAL REPORT

Development and Structure of a Kinetic Energy Weapon System

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Date:	August 15, 1988
Contract No.:	F49620-88-C-0053

Development and Structure of a Kinetic Energy Weapon System

By

Cade D. Coombs

Abstract

This report is an overview of the work I have accomplished on the Kinetic Energy Weapon (KEW) system being developed at the Air Force Astronautics Laboratory. I have discussed the basic theory and role that the KEW will assume as part of the Strategic Defense Iniative program. I have included information on the different areas relating to the Kinetic Kill Vehicle that I have been working on. These areas include: Computers and software applications, design and specific function of the Kinetic Kill Vehicle's internal and propulsion systems, and the operation of the Autonomous Telemetry and Instrumentation Package used during the static test firings to collect data from the vehicle.

I. INTRODUCTION

As a sophomore at Purdue University studying in the school of Aeronautical and Astronautical Engineering, I was very interested in the prospect of working for a company or research laboratory in my field of study. At Purdue, I have completed a full year of classes and next semester I will return as a sophomore. Purdue has offered me the opportunity to expand my education and intellectual skills in the sciences and humanities. As of last semester, I have completed all math courses up to and including elementary differential equations. I have taken classes in physics, both mechanics and electricity & optics, and elementary chemistry. Possessing these basic skills, I considered I was capable of performing simple research in propulsion design. I also considered my communication and computer operation skills as a significant part of my qualifications.

The Air Force Astronautics Lab (AFAL) provides the perfect opportunity for a beginning engineer to gain practical experience and hands on training in an intense scientific environment. During my work period at AFAL, I hoped to accomplish a great deal and learn as much as was possible. In particular, my interests are centered around advanced propulsion systems and technologies for space vehicles. It is apparent that current and future vehicle systems will

require propulsion technology that is reliable, powerful, consistent, and cost effective. If the challenges in design can be overcome, a new vista of spacecraft performance and capability will be achieved. AFAL is one of the best locations for research in advanced propulsion systems. The lab is a prominent leader in the propulsion field and is currently working on several important projects relating to my interests. Upon arriving at the lab, I was assigned to the Vehicle Structures Division and then to the subordinate Analysis Branch. While this branch did not coincide exactly with my objectives, it allowed me to work on a very interesting project that did offer some experience in propulsion systems.

II. OBJECTIVES OF THE RESEARCH EFFORT:

For the last several years the analysis branch of the VSA division has been working on a space based kinetic energy weapon system for the Strategic Defense Iniative (SDI) and upon my arrival I was assigned to this project. The focal point of my research effort was to understand the steps taken to develop such a weapon system. In order to accomplish my project it was necessary to master a great deal of preliminary skills. I had to learn the proper procedures and commands to operate the computers and software applications

available for numerical calculations. I had to learn the reasons behind the origin of the project and what criterion had to be met to enable the deployment of an operational kinetic energy weapon system. Once I had gained a basic understanding of the entire system and was capable of manipulating information, I could work with the specifics of the Kinetic Kill Vehicle (KKV). In particular, I was to learn the mechanics of the KKV's internal and propulsion systems. I also had to become familiar with the Autonomous Telemetry and Instrumentation package (ATIP), which was used to collect data from the static test firings of the vehicles propulsion system.

III. COMPUTER AND SOFTWARE EXPERIENCE:

In order to accurately collect and analyze data, I had to be capable of interfacing with a computer system and its accompanying software applications. I had to become familiar with both the Macintosh personal computer and the VAX mainframe to adequately fulfill my research goals. I used the Macintosh primarily to enhance the effectiveness of my written and oral reports. I used the application called MacDraw for making visual aides to improve my understanding of complicated dynamic scenarios. I used the application word to type documents and reports relevant to my work. I used the Excel software to format test data that could not be directly loaded into

the VAX. I also used the Labview data acquisition software to process and format data received from the ATIP system. The VAX computer system allowed me to handle very large blocks of data. The VAX application known as Matrix-X enabled me to first perform numerical calculations with the test data and then plot the data in an understandable format. I also used the application called MODEC (Motor Optimization Design and Evaluation Code), which allowed me to study the design specifications and flight characteristics of Intercontinental Ballistic Missiles (ICBM's). Using the program, I became familiar with the orbital dynamics and time to orbit potentials of hostile ICBM's.

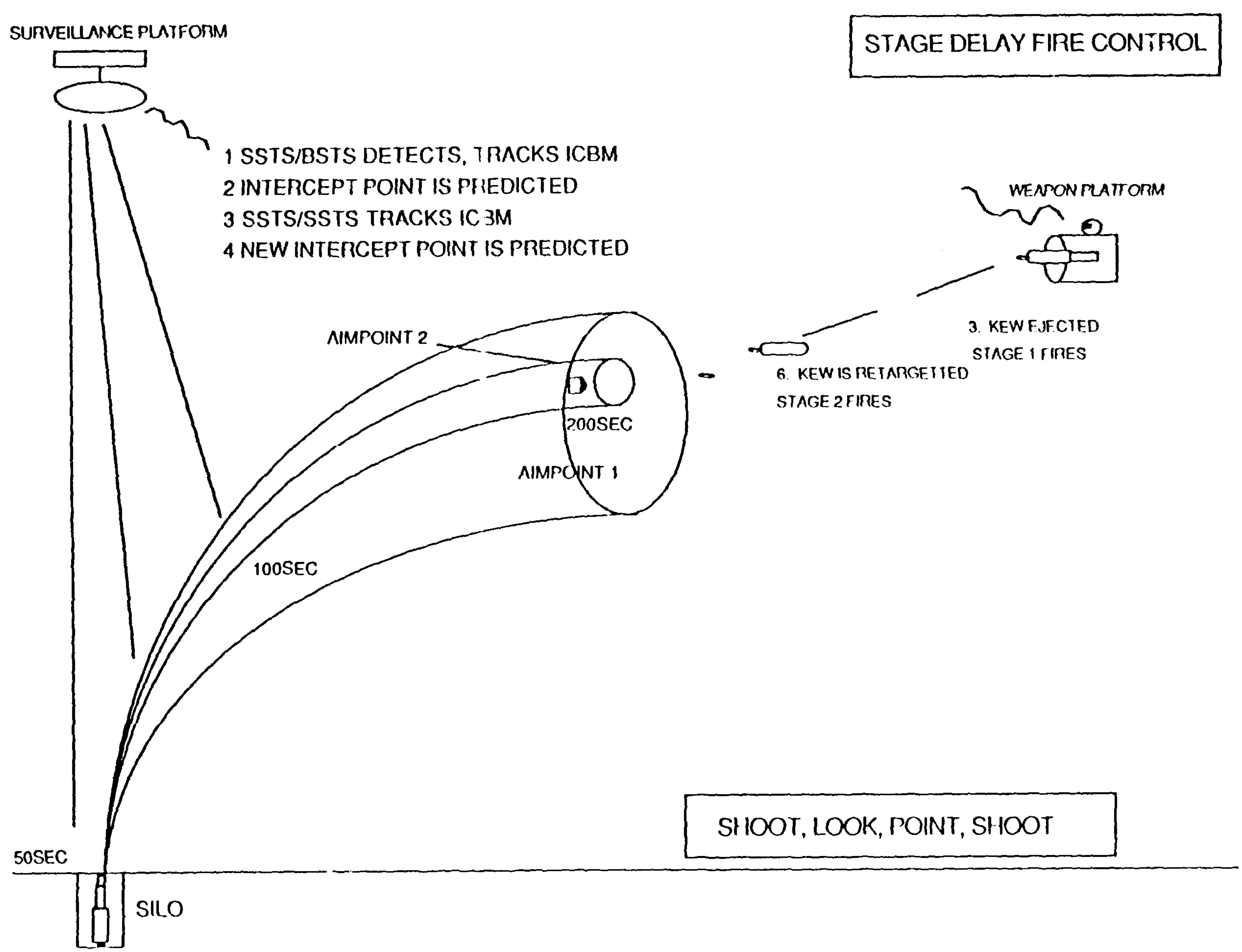
Through experience and practice, I eventually became proficient with the various computer tools available. These tools above all other devices enabled me to quickly and efficiently complete me research goals.

IV. ORIGIN AND REQUIREMENTS OF A KINETIC ENERGY WEAPOM SYSTEM

The origin of a spaced based Kinetic Energy Weapon (KEW) has its roots in the Strategic Defense Iniative (SDI) program currently in the development phase. The KEW is being designed as a possible countermeasure to strategic offensive missiles consisting of mostly land based ICBM's. The KEW or space based interceptor is planned to be deployed on platforms in low-Earth orbit. These platforms will have communication links to surveillance satellites which will monitor hostile missile launches and track any missiles once once

launched. Upon receiving satellite confirmation and target trajectory information, a KEW will be launched from the platform. The KEW will be launched from the platform using a liquid or solid rocket booster. After the KEW is launched from the weapons platform, the KEW will follow an intercept trajectory based on the original ICBM flight path. At midcourse the KEW will fire its second booster stage and alter its course to correct for updated target and interceptor information. The trajectory adjustment by the interceptor will account for intitial targeting errors and possible ICBM evasive maneuvers. Also by controlling the time of the second stage firing, the KEW's range and loiter time can be extended to maximize the probability of a successful mission. Once the KEW has approached within acquisition range, a seeker using the plume of the ICBM will acquire and track the target during the closing phase. In this phase the avionics onboard the Kinetic Kill Vehicle (KKV), the vehicle mounted on top of the first two booster stages, will fire maneuvering thrusters to achieve intercept of the ICBM, thus destroying the ICBM on impact. This sequence of events is displayed in figure #1 on the following page.

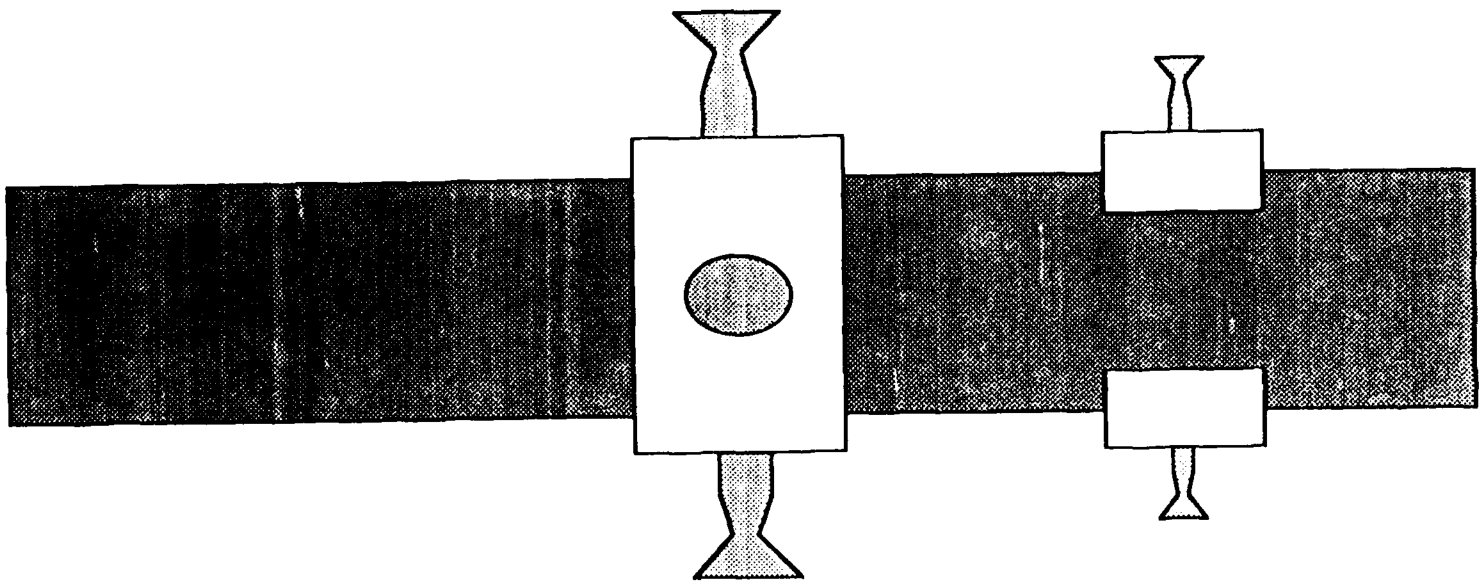
The optimum time to impact the ICBM is during the missiles boost phase. The missile is easiest to track and therefore hit in the boost phase due to its high signature exhaust plume. Destroying the ICBM in this phase also prevents the deployment of MIRV's (Multiple Independently Targettable Reentry Vehicles) carrying nuclear warheads or decoys. With one KEW eliminating numerous reentry vehicles and destroying confusing decoys, there is a substantial



STAGE DELAY FIRE CONTROL
SURVEILLANCE PLATFORM
1 SSTS/BSTS DETECTS, TRACKS ICBM
2 INTERCEPT POINT IS PREDICTED
3 SSTS/SSTS TRACKS ICBM
4 NEW INTERCEPT POINT IS PREDICTED
WEAPON PLATFORM
3. KEW EJECTED
STAGE 1 FIRES
6. KEW IS RETARGETTED
STAGE 2 FIRES
AIMPOINT 2
200SEC
AIMPOINT 1
100SEC
50SEC
SILO
SHOOT, LOOK, POINT, SHOOT

is shown in figure #2. The body consists of a cylindrical shell composed of a composite material. The cylinder contains the fuel and oxidizer tanks, the pressurant tank, and the electronic systems. The nozzles of the propulsion system, which includes four Divert and four ACS (Attitude Control System) thrusters, extend through the vehicle's case. The three tanks positioned inside the shell hold the oxidizer Nitrogen Tetroxide, the fuel Monomethylhydrazine, and helium. The tanks holding the NTO and MMH were specifically designed to regulate fuel and oxidizer flow in such a way that maintains the position of the center of mass. The helium present is used to pressurize the tanks of the fuel system. The four Divert thrusters are designed to provide most of the vehicle's maneuvering capability by producing roughly 400 pounds of thrust. The Divert thrusters are composed of a carbon-carbon material to reduce weight. The ACS thrusters are designed for relatively minute changes in attitude. Each ACS thruster can deliver approximately five pounds of thrust. The ACS thrusters are constructed from a graphite block and covered with a protective coating. Considering both the speed at which the KKV will approach its target and the relative size of the target, it is apparent that the KKV must have precise control over its trajectory. The ACS and Divert thrusters are extremely accurate.

Two static tests were conducted at AFAL to demonstrate the effectiveness of the propulsion system of the vehicle. The static firings involved restraining the vehicle and then firing thrusters. The first static test firing at the lab, known as the Facility Activation



KINETIC KILL VEHICLE

technology, thus reducing the expense and increasing the reliability of the system.

In order to obtain this understanding of the KEW concept and of the KKV in particular it was necessary to spend a great deal of time examining technical reports and other documents. By reading literature on the SDI project I acquired a grasp of how the KEW fit into the overall defense program. By using the MODEC application I was able to gain a better understanding of why the KEW will be placed in low Earth orbit and why the boost phase was the ideal time for interception. AFAL progress reports on the KKV's internal and propulsion systems provided the necessary information to describe the vehicle and its potentials. I also acquired otherwise unattainable knowledge on the vehicle from professional engineers and contractors at the test facility. I was also given the opportunity to inspect the vehicle myself and observe the two static firings of the propulsion system. I was required to demonstrate my understanding of the KKV propulsion and internal systems at a presentation delivered on July 29 for the Universal Energy Systems' summer research fellows. The occasion of this speech gave me the opportunity to practice presenting and reinforce the information I had acquired on the KKV. The presentation was a complete success and a learning experience as well.

V. DESCRIPTION OF THE KKV INTERNAL AND PROPULSION SYSTEMS

The design of the KKV has been completed and almost all of its systems integrated into the vehicle. The vehicles basic configuration

advantage in cost and hardware exchange ratios. The part of the KEW now under development at AFAL consists of the KKV, the final stage of the KEW that will impact the ICBM.

The requirements and minimum capabilities of the vehicle hardware had to be calculated using mathematical models before design specifications could be initiated. Engineers and analysts had to take many different aspects of the weapon system into consideration when establishing the initial system requirements. Since the vehicle was to be deployed in space, the vehicle structure and internal components had to be relatively light. This design constraint was overcome with the use of light weight composite and carbon-carbon materials. The propulsion system had to be able to deliver sufficient lateral thrust to alter the trajectory of the vehicle. The vehicle was built with four Divert thrusters for large changes in attitude and Four ACS (Attitude Control System) thrusters for minute alterations in attitude. The vehicle needed to have a ΔV, the velocity at which the vehicle strikes the ICBM, of at least one Km/Sec. This design specification will be fulfilled at a later date when the exact type of boosters are selected. The vehicles had to provide a stable platform that would allow a seeker device to identify and track hostile ICBM's. The vehicles configuration had to allow for a ten pound payload, which would consist of a seeker device, an IMU (Inertial Measurement Unit), and an avionics package. The two above mentioned requirements are still being tested at AFAL and have not been completely resolved. Finally, the system had to utilize existing electronic and propulsion

Test (FAT), was conducted on July 8, 1988, at the newly refurbished test facility. This test involved single and multiple firings of the ACS and Divert thrusters for one second pulses. The FAT had several objectives that I was involved in: 1) To provide an opportunity to test the data acquisition instruments and techniques, 2) To provide test data so computer analysts could practice data manipulation, and 3) To demonstrate the successful firing of the Divert and ACS thrusters. The second static test firing was conducted on July 21, 1988. The Mission Duty Cycle (MDC) test involved the firing of all ACS and Divert thrusters for an interval of twenty-eight seconds. This test was designed to simulate a theoretical mission of the KKV. My objective for the MDC was to acquire more accurate data on the vehicle systems.

I analyzed the data received from the FAT and MDC test using Matrix-X and then determined the results of the test. The plots of the data conveyed a great deal of information about the vehicles systems. The helium pressurizing system worked well except for a few minor leaks. The Divert and ACS thrusters functioned as expected. The FAT and the MDC tests were completely successful and have provided the groundwork for future tests and development.

V. ATIP DATA ACQUISITION SYSTEM

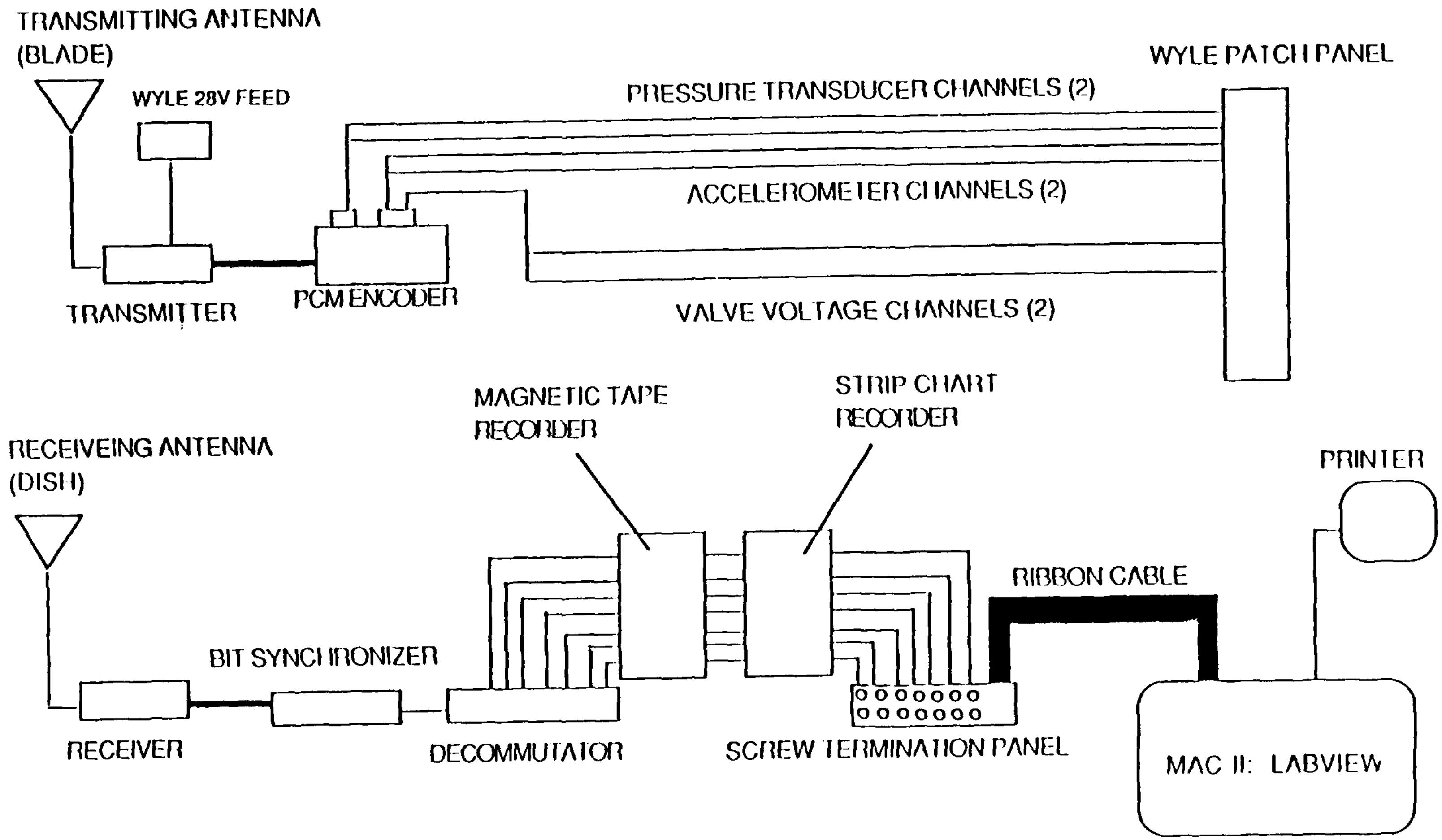
The ATIP or Autonomous Telemetry and Instrumentation Package (ATIP) was developed at the Air Force Astronautics Laboratory

(AFAL) for use in the Kinetic Hover Interceptor Test (KHIT). The system was used in both the FAT and the MDC Static Test Firing. The system was developed to allow data to be recorded from the vehicle via telemetry. The information to be recorded by the system included the data from the flight accelerometers, helium regulator and helium tank, and valve voltage. The ATIP systems purpose is to pickup those instrumentation parameters not available to the flight downlink system due to data constraints.

The ATIP system for the static tests consisted of the vehicle and data acquisition instrumentation. The process by which data was acquired is shown in the ATIP static test schematic. Instrumentation pickups were attached to the four pressure transducer signal out connectors on the patch panel located on the right side of the test stand. The accelerometer pickups were located on the breadboard patch panel at the middle of the stand. One valve voltage was picked up by teeing off from the valve driver housing on the left side of the stand. All pickups were run to the multiplexing encoder patch board located on top of the small table at the left end of the stand. A transmitter was placed on the panel to transmit the multiplexed signal through the S-band blade antenna to the receiving antenna outside.

The data acquisition equipment was set up inside the control room. Major components consisted of the telemetry rack and digital data acquisition system. The receiving antenna terminated at the back of the telemetry rack, attaching to a Microcom S-band Receiver. The

ATIP STATIC TEST SCHEMATIC



receiver then sent the signal through the bit synchronizer, down to the decommutator for demultiplexing. Analog output ports from the decommutator were used to disseminate the filtered and multiplexed signal to the analog tape recorder and digital data acquisition system. A strip chart recorder was also used for real-time data display. The digital data acquisition system consisted of an Apple Macintosh II, LABVIEW Hardware and *software package, and a screw termination* panel.

The ATIP acquisition system worked perfectly during both the static tests. The data from the MDC test was more accurate due to an increase in the recording frequencies used. The ATIP system provided me with the data I needed to draw conclusions about the vehicles systems. The system also provided flight accelerometer data for the vehicle. The successful testing of the ATIP system allows for accurate data acquisition during the hover test of the vehicle.

VII. RECOMMENDATIONS:

The deployment of an operational Kinetic Energy Weapon System would allow this country to intercept and destroy hostile ICBM's, thus preventing horrendous damage from being inflicted upon this nation's resources, people, and culture. The KEW is an imported link in the SDI project and should be pursued with as much vigor as possible. There are a few recommendations I can make that would

significantly improve the development of such a weapon system. The KKV needs to be hover tested to prove that the vehicle is capable of being controlled in flight. The seeker needs to be tested in the environment that the KKV will inhabit. This should include a test in which the seeker can track an actual missile launching from the Earth and entering the atmosphere. The vehicle needs to be reduced in size to decrease weight considerations for space deployment. The rocket booster that will launch the KKV from its platform needs to be selected and integrated with the KKV. Finally, the system should be tested in space as a prelude to its initial deployment.

ACKNOWLEDGEMENTS

I would like to thank the Air Force Systems Command and the Air Force Office of Scientific Research for the opportunity to work as a summer research fellow at Edwards Air Force Base. I also appreciate the opportunity to work at the Air Force Astronautics Laboratory. I must extend my grateful appreciation to Universal Energy Systems and there representative at the lab, Dick Clark, for there help in administrative and employment areas. I would also like to thank everybody from whom I received assistance or guidance during my research period. The advice and support of my mentor, Dave Ductor, have been invaluable in my attempts to complete my research goals. I would also like to thank Dave Barnhart, Chuck Dillon, Bryan Wallace, Alan Weston, and Raymond Klucz for their encouragement and assistance.

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

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FINAL REPORT

Thermonuclear Reaction Bibliography, with Cross Section Data Examination of Four Promising Advanced Reactions

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USAF Researcher: Dr. Franklin B. Mead, Jr.

Date: 12 Aug 88

Contract No: F49620-88-C-0053

Thermonuclear Reaction Bibliography, with Cross Section Data Examination of Four Promising Advanced Reactions

by

Larry T. Cox

ABSTRACT

A bibliography of all known thermonuclear reactions was compiled based on an earlier work by Pass (1987). Many reactions were cross-referenced and a fair number were added. The reference list was expanded in number from eight to thirty sources.

The main focus of the research was finding nuclear cross section data for advanced reactions--those with low amounts of harmful radiation (neutrons and gamma-rays) release. Reactions chosen were d-He3, He3-He3, p-Li6, and p-B11. Data were placed in a graphical representation and comparisons were made between sets of data.

Conclusions and recommendations were made for each area of work. All of the work will be published in an AFAL technical report. Work during the summer also included keeping a fusion propulsion reference bibliography up to date and learning how to use three rocket engine computer simulation programs.

Acknowledgements

I would like to thank the Air Force Systems Command, the Air Force Office of Scientific Research, and the Air Force Astronautics Laboratory (AFAL) for their backing of my research activities. Also, Universal Energy Systems (UES) should be cited for making my internship possible and for coordinating administrative aspects of the program. In particular, Dick Clark and Wayne Roe kept everyone informed of schedules and changes, and looked into areas of concern as needed.

Several people in my branch were of great help to me. Lt Col Homer Pressley was instrumental in my selection into the program, and he kept me informed of my job status while I attended spring semester at Purdue. My mentor, Dr Franklin B. Mead, made my work challenging and rewarding, as well as enjoyable. While under him my knowlege of nuclear fusion and thermonuclear reactions has increased substantially. Dr George A. Beale and Lt Ryan K. Haaland were quick to answer my questions and gave me the chance to observe presentations by contractors in their projects firsthand. Andrew Martin provided expert help with computers, and Larry Austin should be noted for his assistance on my technical report.

I. INTRODUCTION

Nuclear fusion space propulsion represents the next giant step for mankind to boldly go where no man has gone before. Such a system is extremely attractive. High thrust, limited neutron and gamma-ray production, and environmentally safe exhaust products are just some of the benefits.

My job assignment at the AFAL is in the Advanced Concepts Division of the Astronautical Sciences Branch. Within my division I am a part of the Future Technologies Section, whose job is to make futuristic propulsion ideas feasible. Such areas of interest include nuclear fusion, antimatter, antigravity, and space warps. Several projects are underway to explore utilization of fusion for space propulsion. By making fusion propulsion a reality, the safety problems inherent in fission reactor systems may be avoided. Because fusion reactions are so numerous, information for as many as possible needs to be collected in order to decide which one(s) represent(s) the greatest hope for a successful fusion propulsion reactor.

As a student of nuclear fusion engineering at Purdue University, I am interested in entering into the research aspect of engineering upon graduation. I will be returning to the AFAL off and on as a Co-Op student for the next two years. During this time I hope to expand my work in the

areas of thermonuclear cross sections and reactivities, and to create a computer program which orchestrates this information into a valuable tool for researchers in all aspects of thermonuclear research. Along the way I will learn as much as I can, so I will have a better understanding of the principles involved when I return to school. The reverse is also true--I will be able to apply the principles I learn at school to real-life situations. Other benefits are that I can keep abreast of new technology and I can begin to formulate an idea of what research areas I would like to explore when I enter graduate school. Working at the AFAL as a Co-Op will give me an early chance to decide whether I would like to pursue a career as an AFAL employee.

II. OBJECTIVES

At the start of my summer work session, my research colleague, Dr Frank Mead, and I discussed some goals for me to work toward by summer's end. He presented a fusion reference bibliography for me to update and organize as needed. We felt the bulk of my work, however, should concentrate on completing a technical report for the Air Force. It should include an updated bibliography of all known thermonuclear reactions and should investigate the cross section data for four advanced reactions. The reactions to be examined were d-He3, He3-He3, p-B11, and p-

Li6. For both areas, my interpretation of the data and my recommendations for research were to be included.

A third area I worked in was the use of rocket engine computer simulations. These were ISP (AFAL Isp Program), NETAP (Nuclear Engine Transient Analysis Program), and MINERVA (Mission Integrated Nuclear Engine and Rocket Analysis). For the ISP program, I was to write an outline, which would form the basis for a guidebook explaining how to use ISP. I was to learn the use of neutronic data in NETAP, so that I would be able to alter reactor specifications as needed in future simulations. Andrew Martin, another UES fellow, and I shared an office. We were to begin compiling documentation for NETAP and the other computer simulation programs. With usage references, future users of the programs could begin utilizing the simulations quickly and efficiently with a minimum of bookwork. MINERVA is basically a mission simulator, whereas NETAP is used to test a final engine design in a ground run. More precisely, MINERVA simulates the engine's behavior through cooldown, startup, actual run time, shutdown, and pulse coolingand cooldownunt. It avoids the use of nuclear data, which is NETAP's purpose.

As the summer continued, I realized that I would need to devote the majority of my time to work on my fusion

fuel technical report, as it was needed by the end of the work period. My work with the computer simulation programs will increase when I return as a Co-Op, at which time my research into thermonuclear cross section and reactivity data will continue. I will attempt to fit such data into curves and useful equations.

III. FUSION BIBLIOGRAPHY

a. Keeping a bibliography of fusion propulsion references is important because no such document of its type is known to exist. It allows one to quickly determine if the source needed is readily available, as well as allowing one to see if the author of the needed source has written any similar works. Two tasks comprised the majority of the effort: 1. editing entries for correct form, and 2. adding a substantial number of entries.

b. The number of items contained in the bibliography has been increased dramatically--from 121 to approximately 200 sources. A copy of the bibliography exists on a WordStar file in the office in which I worked.

IV. TECHNICAL REPORT

a. The technical report consisted of both a thermonuclear reaction bibliography and an investigation of the available

cross section data for the d-He3, He3-He3, p-B11, and p-Li6 reactions. Compiling the reaction bibliography involved searching through all of the references in the fusion bibliography, as well as going to the AFAL library and consulting additional references. A special attempt was made to cite each reaction with as many sources as possible to insure accuracy and faith in the final product. Sources which could not be found were ordered through the library in order that I would have access to them when I return as a Co-Op. It was necessary to thoroughly check the earlier work by Pass (1987) for errors and to use it as a guide for the updated bibliography.

The four reactions investigated were chosen based on four criteria: 1. no neutron production, 2. no gamma-ray production, 3. exothermic in nature, and 4. achievable ignition. Criteria 1 and 2 were most important in the selecion. Number 3 is easily met by all four reactions. Achieving ignition (criterum 4) was not made a major concern due to the limiting factors of current technology. Data was collected from as many sources as there were available to me. Brookhaven National Laboratory (Cross, 1987) and Los Alamos National Laboratory (Hale, 1981) each contributed significant amounts of data for my use. The "Barn Book" by George Miley (1974) included fitted curves for two of the reactions: p-

B11 and d-He3. None of these sources contained information for the He3-He3 reaction, however. I did find a fitted curve from research done by Good in a report by Crocker (1970), but it only covered a small range of energies. The only other data I could find for it was an informal photocopied document which appeared to contain the information of a correspondence between R. L. Forward and B. Maglich. In it was discussed the p-B11 Migma and the He3-He3 reaction. After finding the data sets, they were entered into a graphics program to create graphs comparing each reaction's data. Based on the degree the data agreed, the curve shapes, and the data origins, assessments were made of the data that was available.

b. By consulting many sources, several of the reactions could be cross-referenced. I was surprised by the number of reactions which were added to the earlier work by Pass (1987). For most reactions, several branches of possible products exist, but usually only one or two produce favorable products. The favorable branches for each of the four reactions are shown in Equations 1 through 4.

$$d + He3 \longrightarrow p + He4 \tag{1}$$

$$He3 + He3 \longrightarrow 2p + He4 \tag{2}$$

$$p + Li6 \longrightarrow He3 + He4 \tag{3}$$

$$p + B11 \longrightarrow 3He4 \tag{4}$$

A reaction should be studied carefully in order to avoid

unwanted products as much as possible. Equation 5 shows the only unwanted reaction for which data was included in the technical report.

$$p + B11 \text{ ---> } n + C11 \quad (5)$$

Not all of the sources used in the earlier work were available, so when they become available in the future, the reactions will need to be checked for correctness. It was found that no significant efforts have been made since the 1950's to discover new reactions by the particle bomabardment technique.

Collection of cross section data for the four examined reactions yielded some interesting developments when the data was assessed. Data for d-He3 was consistent in all sources (Cross, 1987, Miley, 1981, Hale, 1981). It appears to be a likely first candidate for a propulsion fuel, as it seems to possess the lowest ignition temperature, 32 keV (Advanced, 1987), of the four reactions presented here. The He3-He3 reaction has not been researched to any great degree. A possible cross section peak occurs at a temperature of about 3 MeV--which is beyond present technology--is suggested by the informal data that was found. This reaction would be ideal because it is completely aneutronic. Because He3 is extremely rare on Earth, however, a source such as the moon would need to be utilitzed (Wittenberg, 1986, Kulcinski,

1987, Kulcinski, 1986). While collecting data I found both the p-Li6 and p-B11 reactions (Cross, 1987) have branches which produce harmful radiation, but these reactions appear to have negigible cross sections in comparison with the favorable reactions. A resonance peak of 1.6 MeV was indicated by both sources of data for p-Li6 (Cross, 1987, Hale, 1981). Data from Los Alamos National Laboratory (Hale, 1981) showed a resonance peak to exist at an energy lower than those of previously known peaks. This type of finding is what is needed to make fusion propulsion feasible in the near future.

V. ROCKET ENGINE COMPUTER SIMULATIONS

a. I spent a limited amount of time learning to use the computer simulation programs. For ISP I decided which areas should be addressed in a guidebook and assembled in outline form. I made detailed lists of all nuclear data used in NETAP. I observed how MINERVA worked and what output it produced.

b. There is now an outline to use as a skeleton for an ISP guidebook, but changes are likely to made in it. Some of the neutronics data for NETAP did not make sense--many variables were set equal to zero. Mistakes were found in the source code, and were subsequently corrected. Andrew Martin worked as the primary researcher for each of the rocket engine

computer simulations. We concluded that NETAP should be used only when an extremely detailed nuclear engine analysis is needed, because it uses large amounts of memory and can take hours to run. MINERVA is the appropriate program to use when the basic engine design is being determined.

VI. RECOMMENDATIONS

a. The fusion reference bibliography may be used by persons wishing to determine if a needed source is available in the Future Technologies Section. Researchers in the thermonuclear field will be able to use the technical report I have written as a valuable reference. I know of no other work which has compiled all the cross section data available for the four reactions that were examined. All of the cross section research I did will provide a base for my future work as a Co-Op. The information I gathered on the rocket engine computer simulation programs will serve as a starting point for any program documentation I write.

b. Cross section data for any reaction would be a welcome sight. A large database is needed for advanced fuel reactions. Concerning the four reactions discussed earlier, data for He3-He3 would be very beneficial. More data is needed to confirm the low energy resonance peak of p-B11. High-energy cross section data is needed for both the p-Li6

and p-B11 reactions in order to determine if the harmful radiation branches are indeed negligible. As a Co-Op I will continue collecting cross section data and begin finding reactivity data. Eventually a computer program will be written which includes all of this information. Fitted curves will be developed from the data as well. Documentation for each of the simulation programs will be written and published in modules as they are completed.

c. The amount of research I accomplished this summer was limited by the short duration of my stay due to the fact Purdue starts the fall semester in August. In the future I hope that UES can begin the program earlier in the summer to allow students to spend more time in the engineering environment. Working at the AFAL was a rewarding and exciting experience.

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1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

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FINAL REPORT

Utility Programming to Support Data Analysis

Prepared by: Johnson M. Earls

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Department and University: Computer Science, California Polytechnic State University, San Luis Obispo

Research Location: Air Force Astronautics Laboratory, Engineering Design Evaluation Section, RKBA

USAF Researcher: Mr. Terence F. Galati

Date: 29 August 1988

Contract No: F49620-88-C-0053

Utility Programming to Support Data Analysis

by

Johnson M. Earls

Abstract

My work for the summer consisted of programming several small utilities and one major project. The utilities included a graphics drawing program for the graphics terminals in use in my section and several data conversion routines that transform raw rocket-firing data into a usable format for available plotting codes. The major project was to write a new plotting code that would have the same capabilities as the program now in use, but with a better user interface. Version 1.0 of the program, called XPLOT, is available for public use; contact Mr. Terence Galati at the Air Force Astronautics Laboratory, (805) 275-5356, for information.

Acknowledgements

I would like to thank the Air Force Systems Command and the Air Force Office of Scientific Research for sponsoring this program, as well as Universal Energy Systems for their administration of it.

Mr. Terence Galati was extremely helpful and supportive, always keeping the work interesting, and in general, making the summer an extremely informative experience. Mr. Russ Leighton gave me invaluable assistance in programming, and was a great help in debugging and improving my work. Mr. Les Tepe and Dr. Clark Hawk must also be mentioned for their support of all of the summer students in the section.

I. INTRODUCTION

The Engineering Design Evaluation Section of the Air Force Astronautics Laboratory is an intensive user of the Digital Equipment Corporation VAX computer system. As such, the section needs many utilities and programming aids to improve productivity when using the VAX cluster. This group is active in the computer modeling and analysis of rocket motors and liquid engines and in the analysis of data received from related test firings.

When I came to the Laboratory, I looked forward to the prospect of working with the computers. I enjoy application programming; I have been active in for over ten years. I am a Computer Science major, and my school (California Polytechnic State University, San Luis Obispo) has been rated as one of the top universities in the in Computer Science.

II. INITIAL OBJECTIVCS FOR THE SUMMER

My mentor, Mr. Terence Galati, uses the VAX cluster quite a bit for graphing data from the firings of various rocket motors. When I began working at the Laboratory, he had to do much of the work in preparing the firing data for the graphing program by hand.

On my first day at work, I was given two assignments: Learn the graphics terminal that I was to be working on for the summer, and begin converting the raw data that he received into a usable format. These two projects occupied approximately the first half of the summer program.

At the end of the fourth week, I began a new project (at the suggestion of Mr. Galati) to write a new plotting program that would replace TELLAGRAF^{tm}, by Computer Associates, the existing code currently in use. TELLAGRAF^{tm} is a large, multi-faceted program that is quite powerful, but is not very flexible (including the fact that it has a 5,000 point limit on plots) and has poor documentation. I began writing my program (XPLOT) with the specific requirements of the section in mind, which included large data sets (up to 50,000 points), good documentation, and more

flexibility than TELLAGRAF^{tm} offered.

III. DrawPIC

I began the summer by learning the terminal on which I was going to be working. The terminal is a Tektronix 4208, a high-performance, high-resolution color graphics terminal. It has an extensive command language that is accessed through special text sequences that are sent to it. I learned this language and wrote a graphics drawing program. The program (called DrawPIC) accepts input in post-order (or "reverse-polish") notation, which means that all the data that a command is going to use must come before the command is given. DrawPIC is now in its second revision and has two versions. Both versions accept commands only from an ASCII file. The first version, when executed, will ask the user which file to execute, while the second version will pick a random file from the current directory and interpret it.

IV. Data Conversion

While I was working with DrawPIC, I began looking at the raw data files that the section received from previous rocket motor firings. The files came as just a series of columns of data from thermocouples and

other data gathering devices, with a header containing the channel name and the units of each column. I first wrote a utility to extract the data column by column and write each data set to a different file, containing the name of the channel and the units of the data, followed by two columns of data (Time and Value). Treating those as "Neutral" files, I then wrote several more routines that would convert the data to formats usable by TELLAGRAF[tm] and XPLOT.

V. XPLOT

My largest program over the summer was XPLOT. I began writing it in the middle of the fifth week, and finished a major portion of the code by the end of the sixth week. I spent the next four weeks debugging and adding features to the original implementation. I used some of the four-week period to write documentation for XPLOT, which helped a great deal with the programming. By writing both the program and the documentation at the same time, I was able to keep a good level of consistency in the coding and in the command format and response.

Writing this program was a new experience for me; I had never written a program that was as long as XPLOT, which is over 7000 lines of FORTRAN. I used a

graphics library called DISSPLA[tm], which is maintained by Computer Associates (it was originally written by ISSCO, which Computer Associates recently acquired.) TELLAGRAF, also maintained by Computer Associates, was written by ISSCO as a front-end to DISSPLA, so I knew what DISSPLA was capable of, even though the documentation for DISSPLA is more difficult to read than that of TELLAGRAF.

Included at the end of this report is a series of sample plots generated by XPLOT. These show both its capabilities and its limitations.

Figure 1 : This is a plot of four thermocouples from the June, 1987 firing of a Morton Thiokol Star 30 rocket motor with a Novoltex exit cone. This plot shows the automatic scaling of the x- and y- axis.

Figure 2 : This plot is an enlargement of the spike area between 1.4 and 1.7 sec of thermocouples 3 and 4 from Figure 1.

Figure 3 : This plot comes from data from the firing of a Minuteman III third stage motor. This motor had an overpressurization, which caused the cone to fall off the motor two seconds after ignition. since the firing was done at simulated

altitude, the flames were left to freely expand, enveloping the aft end of the case. The motor casing failed at 28 seconds, creating massive deflagration and damage to the test cell. Notice that the data returns to about 1700°F at 10 seconds; this happens to be the melting point of the thermocouple extension wire, which then fused to form new temperature sensing junctions.

VI. RECOMMENDATIONS

I feel that the XPLOT program should be enhanced to include multiple plots per page, message text blocks that can be placed anywhere on the page, etc. I am applying for a Cooperative Education position at the Astronautics Laboratory in the Engineering Design Evaluation Section. I would like to continue developing XPLOT, as well as designing and programming new engineering applications in the future.

VII. REFERENCES

Reference Manuals:

1. DISSPLA User's Manual, version 10.5, Integrated Software Systems Corporation (ISSCO), 1985

2. The VAX/VMS Reference Set, version 4.7, Digital Equipment Corporation, 1987

3. TEK Reference Guide, 4200 Series, Tektronix, Inc., 1986

4. TELLAGRAF User's Manual, version 6.0/6.1, Integrated Software Systems Corporation (ISSCO), 1985

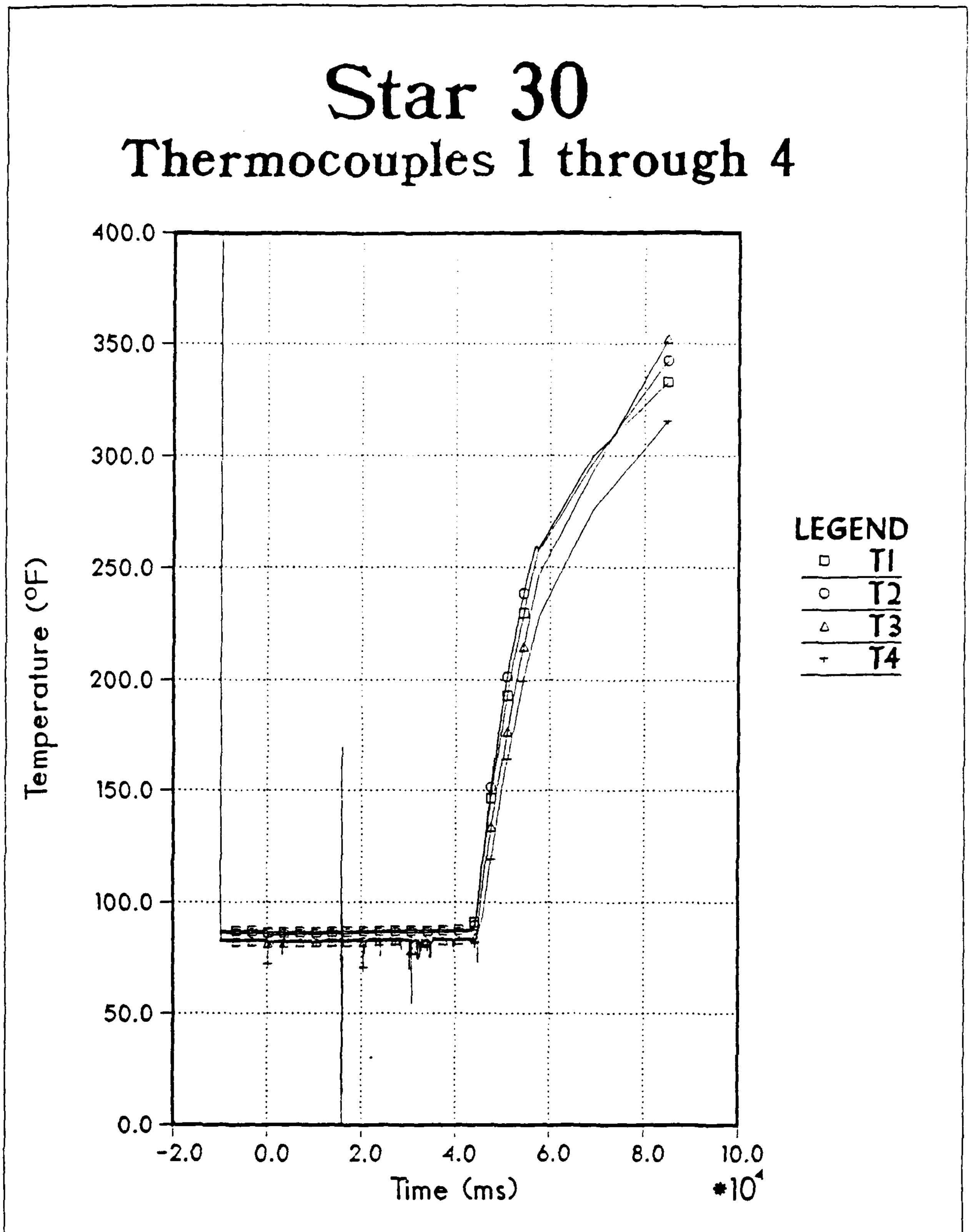

Figure 1 - Thermocouples 1 through 4, Morton Thiokol Star-30 motor with Novoltex exit cone

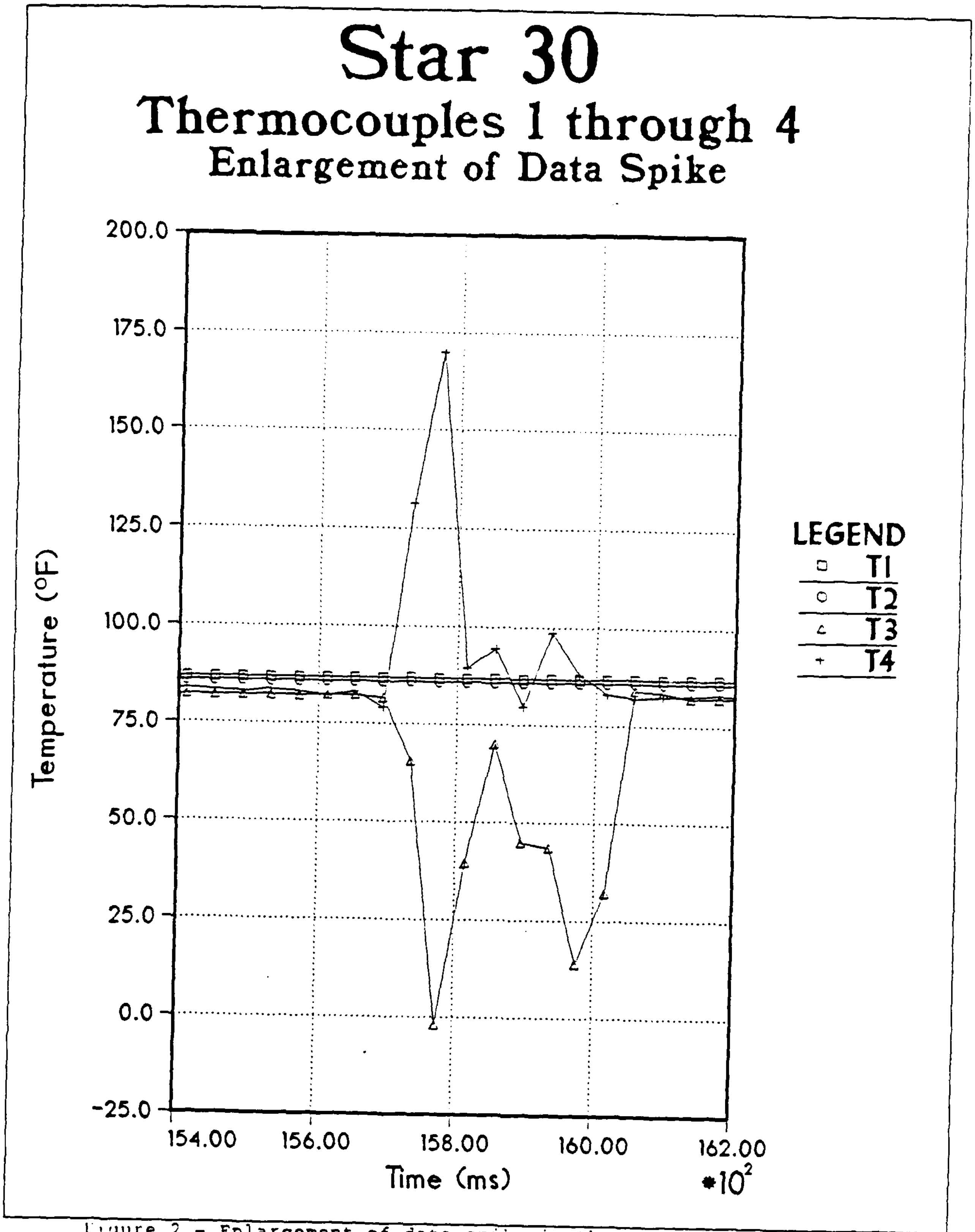

Figure 2 - Enlargement of data spike in thermocouples 3 and 4, Morton Thiokol Star-30 motor with Novoltex exit cone

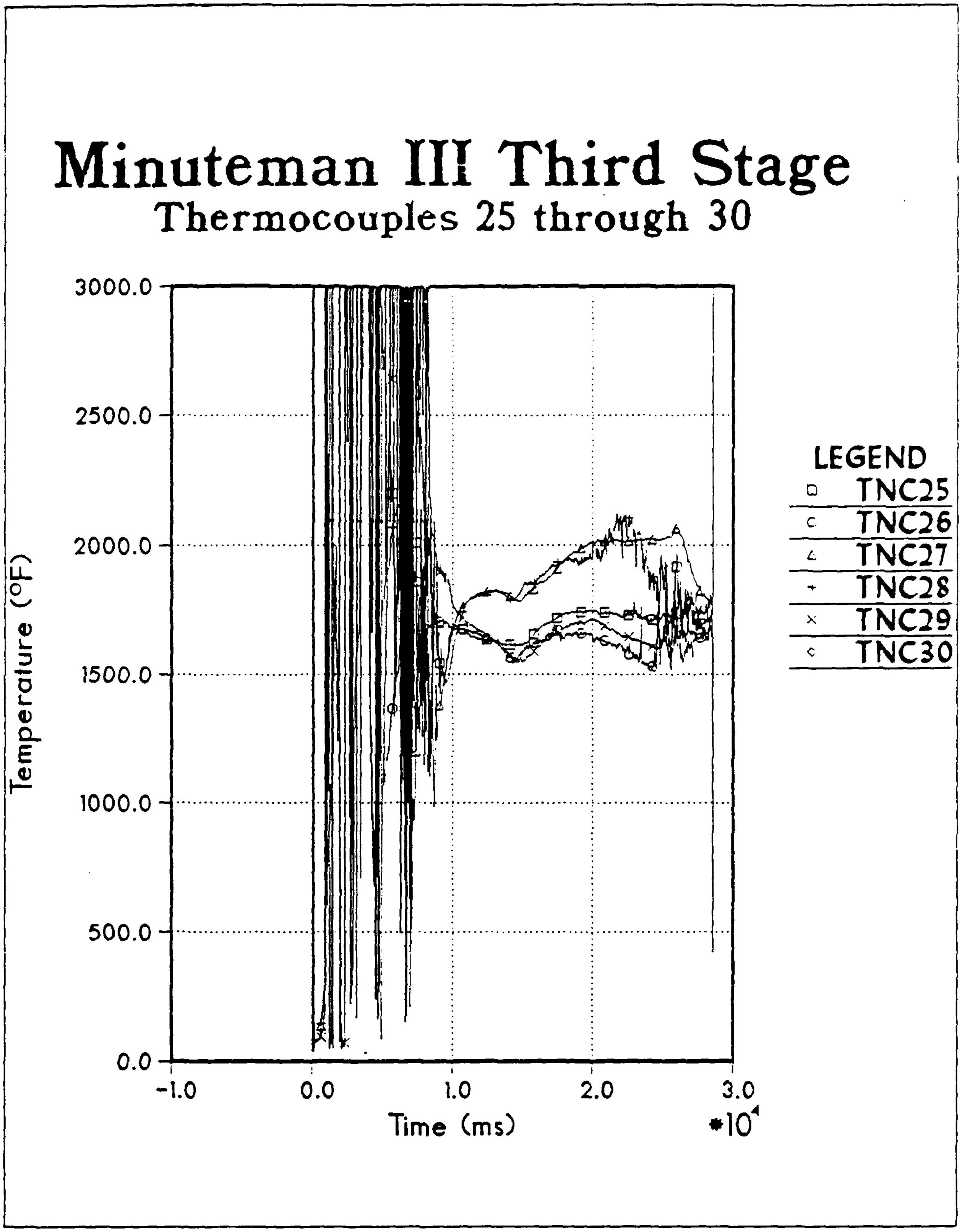

Figure 3 - Minuteman III third stage motor, Thermocouples 25 through 30.

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FINAL REPORT

PATRAN Finite Element Analyses

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USAF Researcher: Mr. Terence Galati
Date: 19 August 1988
Contract No: F49620-88-C-0053

PATRAN Finite Element Analyses

by

Christopher E. Gazze

ABSTRACT

Two computer modeling analyses were conducted using the PATRAN finite element modeling code and the P/STRESS finite element analysis code. For the first, a supporting beam for a laser tracking unit to be used in a test of the KHIT vehicle, a three dimensional model was created and meshed with hex elements. Analysis using P/STRESS found that natural frequencies of the support were very close to frequencies which would be present during the test, indicating the possibility of unwanted resonance occurring. For the second project, a two dimensional, cross-section of a Minuteman III third stage nozzle assembly was created with patches and meshed with quad elements. Analysis of this model is ongoing.

ACKNOWLEDGMENTS

First, it is necessary to recognize both the Air Force Office of Scientific Research and Universal Energy Systems whose sponsorship made this research possible. Dick Clark's work as an administrative liaison was greatly appreciated.

On a more personal level, I would like to thank Terry Galati for his constant help and guidance in all phases of my work. My gratitude also extends to Russ Leighton for his technical advice; to Les Tepe for his support; to my colleague Johnson Earls who was an endless reservoir of computer aid; and to my partner on both projects, Brian Thornton. Finally, I would like to express special thanks to Wayne Roe for his invaluable help in finding me a place to live and roommates for my summer stay, and to Clark Hawk whose efforts were directly responsible for my assignment at the lab.

I. INTRODUCTION:

In an environment such as that which exists at the Air Force Astronautics Lab, there is often a need to perform complex analyses of structures before they are used in hazardous experimentation. Recognizing this need, the lab recently formed the Engineering Design Evaluation Section under the Propulsion Division. Through the use of powerful computer modeling programs, this new group is able to accurately predict the behavior of complex, high-technology structures performing in extreme operational envelopes, with the goal of protecting expensive components and preventing accidents during the testing of margin critical designs.

One important tool utilized by this new section is the PATRAN finite element modeling code. PATRAN, by PDA Engineering, uses mathematical methods to represent physical entities. Models generated in this way can then be submitted to one of several analysis programs to determine stresses and deformations brought about by a wide variety of pressures, temperatures, and loading conditions. Finally, PATRAN's high quality graphics make results clear and easy to decipher.

I had no experience with either structures or finite element techniques upon coming to the lab; however, my background in mathematics, physics, and drafting gained during my first year

at Penn State proved to be a more than adequate basis to begin the modeling process. For this reason, I was assigned to this new section for the duration of my stay at the Astronautics Lab.

II. OBJECTIVES:

I was tasked with two separate structural analysis projects during this time. The first problem, an analysis of an I-beam support, was conducted for the Strategic Defense Initiative's Kinetic Kill Vehicle Hover Interceptor Test (KHIT) project. The second, an evaluation of a third stage Minuteman III nozzle assembly, was an in-house project being supervised by a project engineer at the lab.

The KHIT vehicle is ultimately intended to intercept intercontinental ballistic missiles in space. The beam in question supports a laser tracking unit and controller which are needed during a hover test of the vehicle scheduled for later this year. Designers were concerned that vibrations in the building, set up by machine gun-like pulses from the vehicle's eight motors, might add a dynamic stress increment of sufficient intensity to shear the supporting bolts (which hold the beam 27 feet above the floor). Concern was also expressed that any excessive vibration of the beam, caused by a resonance condition, would impede performance of the laser

tracker. To solve these problems, it was necessary to compute the existing stresses on the bolts and to accurately determine the dynamic behavior of the entire support assembly.

The Minuteman nozzle is the product of French technology called NOVOLTEX which utilizes state-of-the-art carbon-carbon composites that are stronger than steel, lighter than aluminum, and stiffer than titanium. As part of ongoing research, several different nozzle configurations are being tested with various rocket motors. In this particular case, the components of interest were the throat and exit cone assemblies. A structural analysis was necessary to insure that the nozzle could withstand the high pressures and temperatures of the test without failing.

III.

a. To solve the beam problem, both a static stress run and a dynamic behavior run were performed using the P/STRESS analysis code, PATRAN's linear version of ANSYS. The models used in these runs were three dimensional representations of the I-beam, endplate, channel rails, and bolts created with PATRAN. Additional components such as the laser tracking unit and controller, not installed at the time of analysis, were simulated with steel plates of equivalent weight (Figure 1).

During the subsequent paving of the model with hex elements, smaller meshes were used in the endplate, bolts, and I-beam where greater resolution of the results was desired. Also, element aspect ratio was kept as near to 1 as possible in areas of interest in a similar attempt to minimize solution error. Originally, the model was divided into almost 3,000 elements; however, limitations on problem size for the AFAL's Vax 8650 forced this number to be cut back to around 1,500 for the stress analysis and 1,200 for the dynamic. Elements deleted for the latter case were all taken from the endplate as the resolution in this region necessary for the stress run was not needed during the dynamic.

b. The results of the static run, performed under inertial loading conditions and with the beam fixed in place only at the bolts, showed high stresses as expected along the top edges of the bolts at their junction with the endplate. Maximum shear stresses were approximately 2000 psi; z-normal (tensile) stresses ranged up to almost 5000 psi. From this data it was estimated that the bolts could support a load twice that of the beam assembly before shearing.

Identical conditions were applied during the dynamic analysis to compute natural frequencies of the beam. While these frequencies ranged from 27 Hz in the first mode to 1320 Hz in the fourteenth, the one of most interest, 126.8 Hz, occurred in the fourth mode. This frequency is critical because it

lies very near the 128 Hz operating frequency of the laser tracking unit. Figure 2 illustrates the dynamic behavior of the beam in this fourth mode.

IV.

a. Because the Minuteman nozzle was axisymmetric, it was only necessary to model a two dimensional cross section (Figure 3). Quadratic, axisymmetric quad elements (quad/8/2) were chosen for the phase II model with fine meshes being included around the thread region and along the exit cone. As it was also decided to run this problem through the ABAQUS code, an identical model was copied from the phase I geometry and paved with quad/8/7 elements to insure compatibility. Finally, the outline was rotated around the axis of symmetry to form the last model, a three-dimensional, patch representation.

b. At the time of this report, only a test analysis had been run on this model in order to guarantee its integrity. The nozzle held up well with only very slight deformations near the tip of the exit cone. High stresses were present in the thread region; however, the severity of these stresses will not be fully known until thermal conditions have also been applied. Final analysis currently awaits data on material and boundary conditions to be applied. Some of this data will be predicted with the Solid Propellant Performance program (SPP),

and will be applied and processed by other project engineers after I have left the lab.

V. RECOMMENDATIONS

KHIT engineers have been advised to apply dampening devices to their support beam because of the danger of resonance at the 128 Hz frequency. Such a condition could seriously damage the controller unit and possibly cause the bolts to fail. In addition, it was recommended that they search for any other frequencies present during the test which match the ones determined in the analysis so that additional dynamic behavior plots of those modes can be provided. Finally, follow up analysis of any new designs was suggested.

Because the data currently available on boundary conditions (calculated by SPP) was obtained from an analysis of a nozzle very different specifications from the one in question, it is recommended that another SPP run be performed using the parameters of this nozzle. Following this revision, analyses with P/STRESS and ABAQUS are called for. If these tests indicate that appropriate margins of safety have been met, it is then recommended that the test proceed as planned.

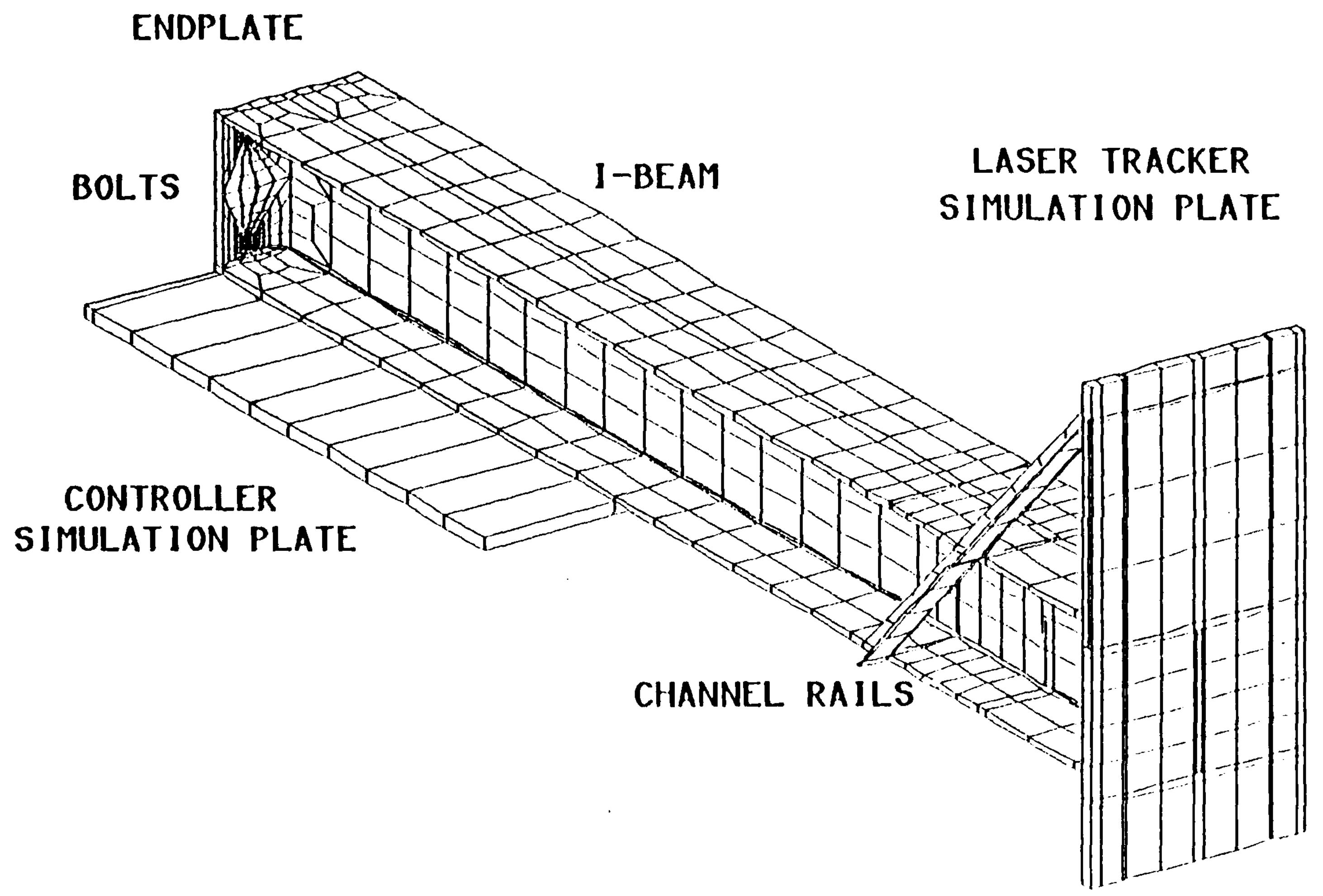


FIGURE 1: KHIT LASER TRACKER SUPPORT

FIGURE 2: DYNAMIC BEHAVIOR OF LASER TRACKER SUPPORT

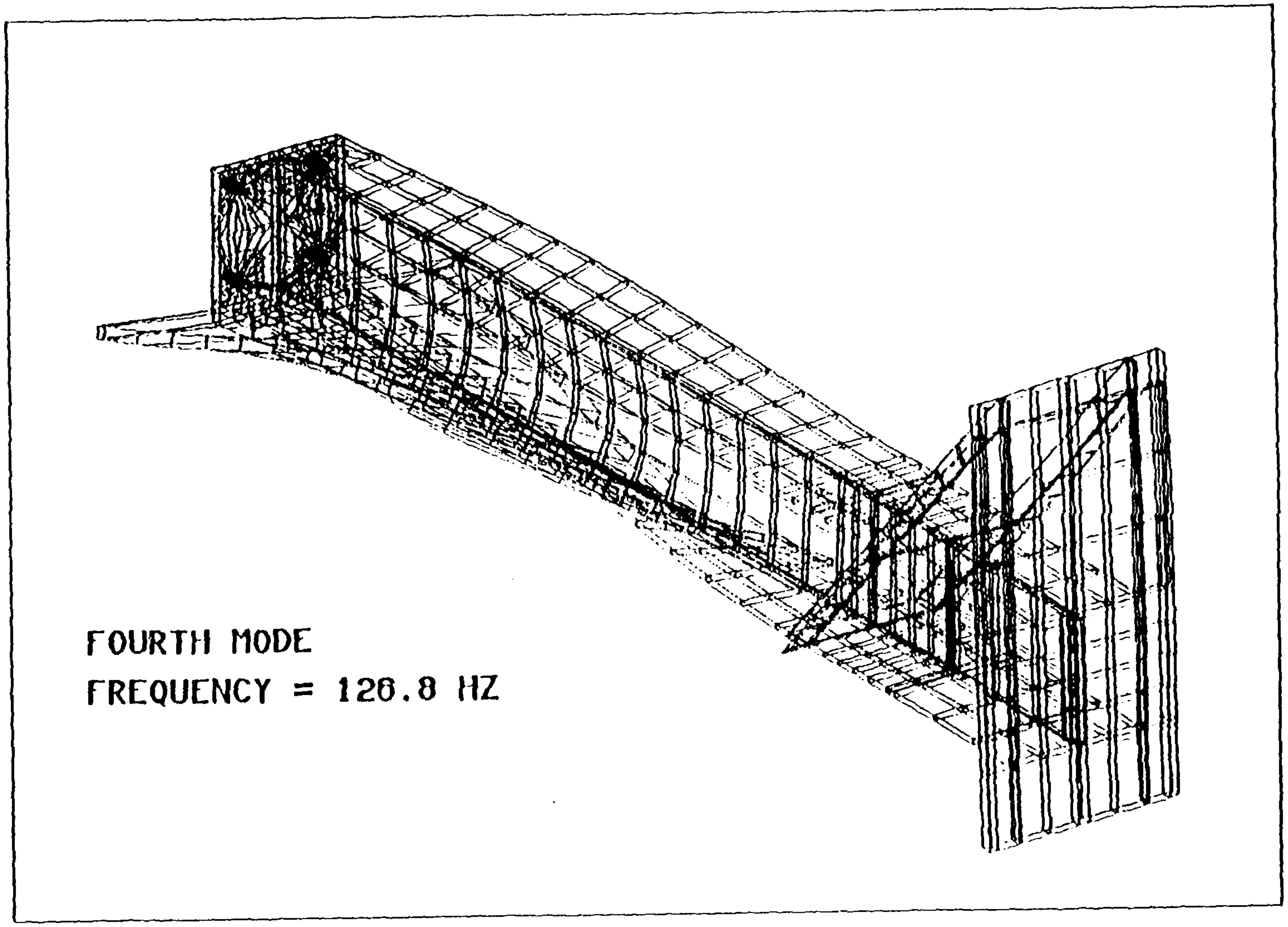
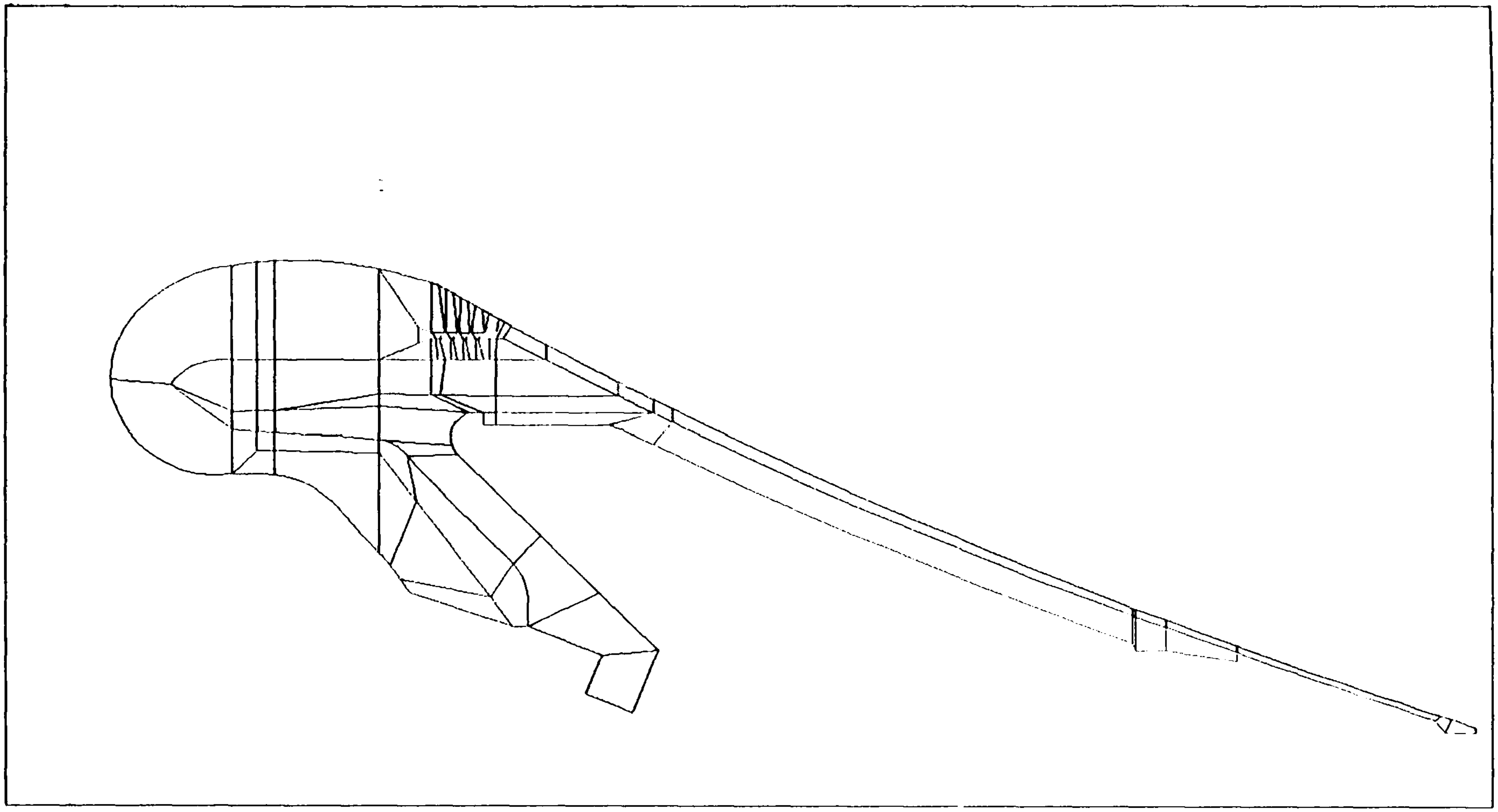


FIGURE 3: CROSS-SECTIONAL MODEL FOR MINUTEMAN NOZZLE ASSEMBLY



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FINAL REPORT

INSULATION COMBUSTION AND ARTIFICIAL INTELLIGENCE EXPERT SYSTEMS

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USAF Researcher:	Captain Marlow Moser

Date:	24 Aug 88
Contractor No:	F49620-88-C-0053

INSULATION COMBUSTION AND ARTIFICIAL INTELLIGENCE

EXPERT SYSTEMS

by

Gregory M. Hall

ABSTRACT

My work at the Air Force Astronautics Laboratory involved two major projects. The first project, with which I spent most of my time, dealt with the head-end corrosion problem in ballistic missiles. The objective was to create a relatively inexpensive way to test different types of insulation as it would burn under flight-like conditions. My main task was to design different parts of the apparatus which we would be using to do the testing.

My second project with the Air Force Astronautics Laboratory involved computers. Angie Knappenberger, another summer fellow, and I researched many aspects of expert systems. From our limited knowledge we felt the purchasing of an expert system at this time would be inappropriate for our division to do. However, we also felt that in time the benefits will outweigh the problems of today.

Acknowledgements

I wish to thank the Air Force Astronautics Laboratory/Aerothermochemistry Section, the Combustion Laboratory, the Air Force Systems Command, and the Air Force Office of Scientific Research for sponsorship of this program. I also extend my gratitude to Universal Energy Systems for granting me with this valuable opportunity.

My experience was enriched by several of my co-workers to which I also wish to thank. Dr. Phil Kessel was very helpful in introducing me to the work and projects of this section. Dr. Larry Quinn inspired me with his sincere concern. Capt. Ken Philippart, Capt. Joe Cor, and Elizabeth Slimak were always there to answer any of my questions no matter how trivial they may have been. The same was true of Tracy Christensen who seemed to be there in the lab whenever I needed assistance. But my greatest thanks goes to Capt. Marlow Moser who was my mentor. Through him I learned much more than I could have ever anticipated. He understood my level of education and never hesitated to teach me any concept regardless of its simplicity.

I. INTRODUCTION

As a sophomore in Aeronautical and Astronautical Engineering at Purdue University with technical graphics and computer programming in my background, I was capable of performing my various duties during this summer's research program.

One of these duties was to design a protective barrier around the centrifuge which we will be using to spin our insulation burning combustion bomb. Which leads to another task of mine - to design the actual combustion bomb. This took a considerable amount of time as the bomb design underwent many modifications since there were many factors to consider in its design.

Also, Angie Knappenberger and I were given the task of researching expert systems as they relate to artificial intelligence. Our section may consider purchasing an expert system shell for propellant formulation design. Basically, we were to obtain as much knowledge on the subject as we could and be able to rate some of the systems available.

II. OBJECTIVES OF THE RESEARCH EFFORT:

Before arriving at the Air Force Astronautics Laboratory, I was unsure of what my responsibilities would be and therefore I couldn't set any specific goals.

Upon my arrival I found out that my main goal would be to assist Capt. Marlow Moser by designing parts and objects in his spin window bomb project. Initially I was to design a protective barrier to surround the centrifuge. After a few weeks I became responsible for the design of the combustion bomb that the insulation would be burned in.

With only a few weeks remaining in my summer session, another task was added to my responsibilities. Along with Angie Knappenberger, I was to research expert systems. Ultimately we were to obtain enough knowledge to discuss the possibility of purchasing an expert system to aid in propellant formulation with our branch chief, Dr. Quinn; and our section chief, Dr. Kessel. There was also the possibility of speaking with Software Engineering Associates (SEA) on the subject. Angie and I collected our knowledge from many texts and magazine articles.

III.

a. Before beginning any design work I had to first gain an understanding of the project as a whole. I had to learn more about solid rockets, how the insulation burned during flight, what insulation was being used, and details such as what temperature the insulation burned at in the rocket. I also had to learn about the char layer that forms on the insulation during combustion. There are several theories on why we are having trouble with the insulation and I needed to understand why we were focusing on the one we were.

After gaining the initial information I next needed to obtain some technical skill. I began learning the Teknicad program for computer graphics design. This all aided me in my designing for Capt. Moser.

In preparation for my expert system project Angie and I had a meeting. We came to the conclusion that neither of us had much of a background with artificial intelligence and even less with expert systems. We then spent much time on main base and at the astronautics laboratory in libraries researching all we could. Outside the libraries we read and followed examples of expert systems. We periodically held discussions to check each others understanding.

b. My efforts towards helping Capt. Moser led to several accomplishments. Personally I was given great insight into what it takes to be an engineer; which is an invaluable opportunity that one can never get from any university. I also became comfortable using a computer for design. This was beneficial as I had no previous experience with computer design. For the project, I completed the protection barrier design as well as the combustion bomb design. Before I left, I explained all about my combustion bomb designs to Capt. Moser so he could submit them to the machine shop for construction.

From our research on expert systems, Angie and I concluded that considering the time requirement and high cost to obtain an effective system for aid in propellant formulation, the cons outweighed the pros. The cost plus the minimum five man-years needed to start up the system did not, in our opinion, justify the few rewards the system offered.

IV. RECOMMENDATIONS:

a. The design work I accomplished while at the laboratory has been implemented. The findings Angie and I have found and expressed towards expert systems have found little opposition.

b. Captain Moser's project will be continued at the Air Force Astronautics Laboratory. Although none of the actual research pertaining to expert systems will be done by either Angie or me, we both feel that an expert system would be a better investment in the future when the cost and time factors are reduced.

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

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FINAL REPORT

Mode One Interlaminar Fracture of 2-D Carbon-Carbon

Prepared by: Bruce Jackson Hinds III

Academic Rank: Sophomore

University: Harvey Mudd College

Research Location: USAF Astronautics Laboratory

USAF Researcher: Dr. Peter Pollock

Date: August 18, 1988

Contract No: F49620-88-C-0053

Mode One Interlaminar Fracture of 2-D Carbon-Carbon

by

Bruce Jackson Hinds III

ABSTRACT

Kaiser Aerotech type "C" 2-D carbon-carbon was tested for interlaminar fracture toughness and interlaminar energy release rate. The test used mode one delamination with the double cantilever beam (DCB) specimen. Most tests produced multiple cracks between different plies.. Approximate values of interlaminar fracture toughness and energy release rate were found, with the fracture toughness very similiar to that of graphite.

ACKNOWLEDGEMENTS

I would like to thank the Air Force Systems Command, the Air Force Office of Scientific Research, and the Air Force Astronautics Laboratory for making this research opportunity a reality. It is a most generous program that allows undergraduates the opportunity to be a part of the research process..

A great deal of thanks is due for Dr. Pollock.. He has certainly been more of a friend than a mentor. He taught me so much about the educational system, research world, research techniques, and even mechanical engineering. "Dude, thanks"

Many thanks for Richard Thomsen and Clare Debaets for solving my burdensome computer problems. Ernie Butler deserves thanks for his machining and tolerating my use of the machine shop. Dick Clark was a helpful focal point advisor and really kept on top of matters. Finally I would like to thank the members of the components lab for being hospitable and helpful.

I. Introduction

Two dimensional carbon-carbon composites are composed of plies of carbon fiber fabric that are laminated together. These layers are bonded together by a graphite matrix. The in-plane strength of the composite is mainly derived from the carbon fibers in the cloth. The function of the graphite matrix is to hold the carbon fiber plies together. The strength of the graphite matrix is not near that of the carbon fibers. When a component, such as a rocket nozzle, is designed, the fibers are orientated to receive the vast majority of the stresses. Yet it is inevitable that the graphite matrix will receive stresses. These stresses might separate the carbon fiber plies, resulting in delamination and failure of the component.

The Components Laboratory at the USAF Astronautics Laboratory is interested in the mechanical properties of composite materials. Knowing these properties is essential in the designing of components. Thus, knowledge of the interlaminar strength of carbon-carbon will prove to be beneficial in the production of carbon-carbon components.

I am presently a Sophomore at Harvey Mudd College. During the summer of 1987 I worked at the AFAL in the UES High School apprenticeship program. I worked on projects to find the mechanical properties of carbon fibers and graphite. That experience proved helpful in testing the interlaminar properties of carbon-carbon.

II. OBJECTIVES OF THE RESEARCH EFFORT:

The objective of this research effort is to find interlaminar fracture toughness (K) and energy release rate (G) of 2D carbon-carbon. Mode One interlaminar fracture is the application of stresses normal to the composite plies. In addition to finding fracture toughness and energy release rate, the test will note the behavior of the delamination process.

III. Method

The Double Cantilever Beam (DCB) test was chosen because of it's slow crack growth and easy calculations of energy release rate and fracture toughness. A DCB specimen has a crack running partially through the length of the specimen. The crack runs parallel to the plies. The material above and below the crack act as cantilever beams. The crack must be centered in order to form beams of equal thickness. Load is then applied at the end of the beam. This produces streses that extend the crack down the length of the specimen. According to DCB theory the fracture toughness can be found by equation (1) and energy release rate by equation (2).

$$K = a \times P / \sqrt{(w \times I)} \qquad (1)$$

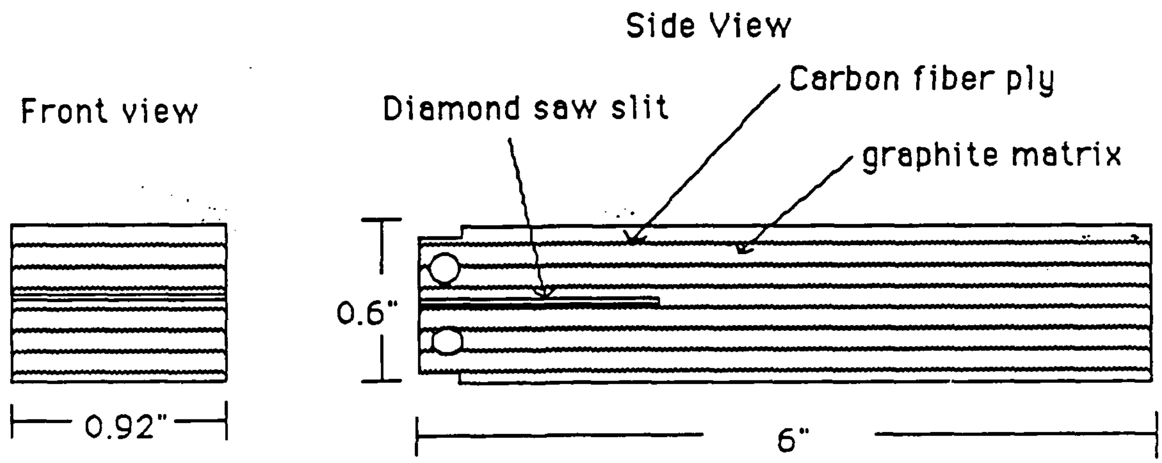
$$G = P^2 \times a^2 / (w \times E \times I) \qquad (2)$$

Where a is crack length, P is critical load, w is width of specimen, I is moment of inertia, and E is Young's modulus.

The test was performed using an Instron tensile test machine, MTS extensometer, cathetometer (optical microscope that measures

distance), and MiniDas data acquisition computer. Proper fixtures and calibrations were made. The specimens were cut from a plate of Kaiser Aerotech type "C" 2-D carbon-carbon. The specimens were cut into 6' (length) by .92' (width) by .6" (thickness) strips with the plies of carbon fiber cloth running the length of the specimen. The plies were laminated through the thickness of the specimen. Two one tenth inch holes were drilled near the end of the specimen. One centered .2" from the top of the specimen and the other .2" from the bottom. The load was applied through the holes with a shackle apparatus. A shackle apparatus was used for applying the load instead of hinges because it was unreliable to bond hinges to the surface. Above and below the drill holes, grooves were cut on the specimen surface to allow the extensometer to be attached directly above the loading plane. A .015" wide diamond saw slit was cut 1.125" down the length of the specimen. This slit acted as an initial crack between the plies, as depicted in figure 1.

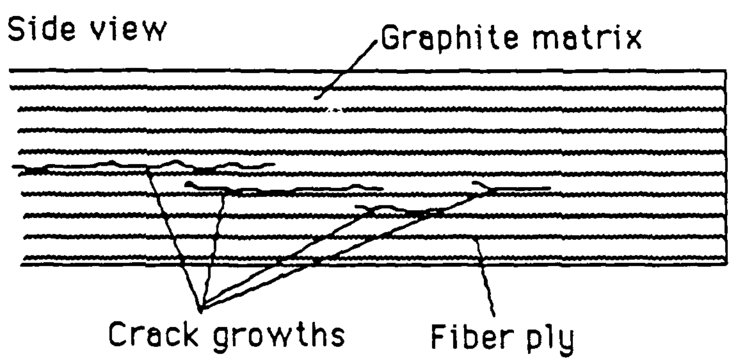
fig. 1



The test procedure was as follows. First the specimen was loaded until a crack propagated approximately 1.5 cm. The crack length was then measured with a cathetometer on both sides of the specimen. The specimen was then unloaded. This process was repeated five to six times. Then the specimen was loaded to failure. For every loading-unloading cycle, load and displacement data was recorded on data acquisition computers.

Only two of the eleven tests followed the standard DCB results. The majority of the specimens had several interlaminar cracks instead of a single central one. These cracks were formed between different plies (see figure 2). To describe the multiple cracks, drawings of the crack growths were made for each loading. Another difficulty with the test was the measurement of the crack length. Often the side of the specimen had a small areas of higher porosity which made it difficult to follow hairline fractures. Uncertainties of crack lengths could easily exceed ten percent in because of porous areas.

fig.2 Example of multiple cracks



Because of of the multiple crack growths a different approach ,instead of the DCB theory, had to be considered The DCB theory

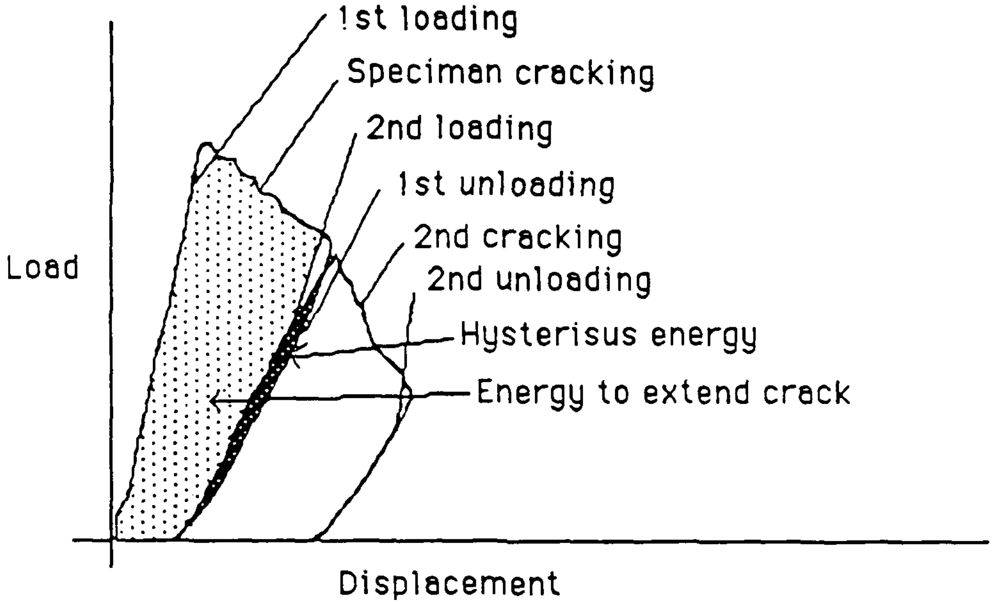
assumes there is a single crack length. The two specimens which had a single crack still apply to the DCB theory. For the rest of the tests the definition of energy release rate can be useful.

$$G = \text{energy to propagate crack} / \text{crack surface area} \tag{3}$$

The area under a plot of load vs displacement during a loading-unloading cycle would give the energy used during the cycle. In graphite materials there is a significant hysteresis, this test was no exception. During a test the specimen was loaded just short of the critical load then unloaded. The hysteresis formed by this was the same as the hysteresises seen in the course of the test. Thus the energy lost in bending the beams is the same as the energy in the hysteresis loops. Energy absorption can occur in the bending of the beam and extension of the crack. Thus the energy absorbed to extend the crack is the total energy under the load-unload curve minus the hysteresis energy. The energy in the hysteresis loops seems to be a function of the displacement of the beam, not the load applied. There was appreciably more hysteresis energy in large beam displacement at low loads than that of small displacement at high loads. Thus it is appropriate to subtract the hysteresis energy at the end of the loading cycle (where beam displacement is greatest), or in other words find areas between loading curves (see figure 3).

Fig. 3

Load vs displacement for two loading unloading cycle



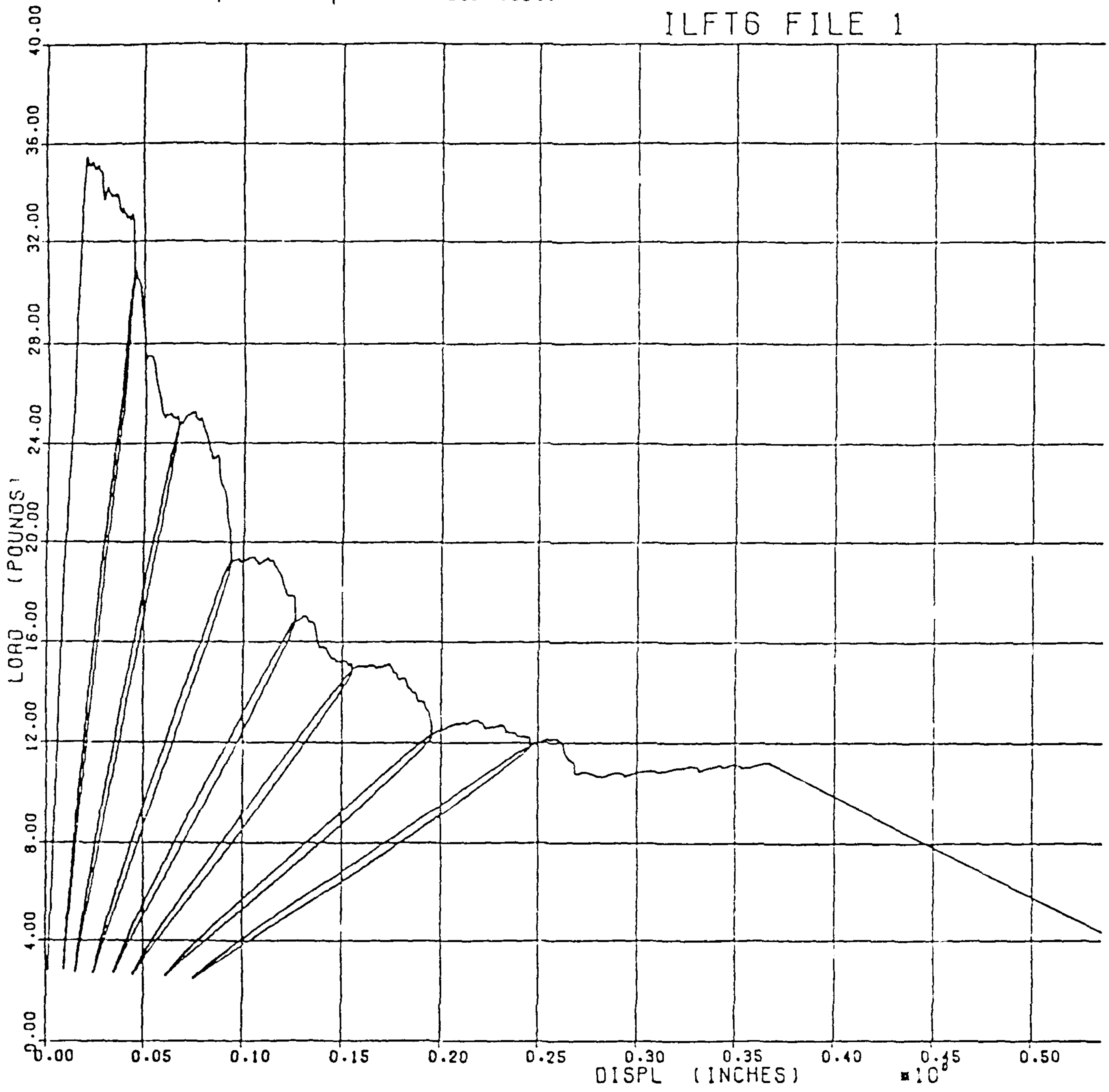
In the case of multiple cracks, if the amount of growth for each crack is summed and multiplied by the width of the specimen the total amount of new crack surface area is found. The energy release rate would be the energy between loading curves divided by the new crack surface area. This assumes that the location of the crack does not effect the energy needed to extend it.

In the course of my works I have completed the experimental work and have calculated some rough values of energy release rates. G ranged from .056 to .090 ft lbs/ in^2. In the two proper DCB tests K values ranged from 900 to 1200. psi$\sqrt{in}$ In comparison K for graphite is approximately 890 psi$\sqrt{in}$. The interlaminar strength of Carbon-Carbon is not much greater than that of graphite.

IV. Recommendations

The DCB test gives a good idea of the interlaminar fracture toughness and energy release rate . To improve the accuracy of the test steps should be taken to have only one crack propagate through the specimen and a have a more reliable method of measuring crack length. The cause of the multiple cracks is not certain. The specimen were not machined to the highest standards and were slightly unsymmetrical. Yet the two specimens that had only one crack were not superior in their machining. The formation of multiple cracks could be inherit to the material. In order to determine which is the cause of multiple cracks specimens should be precisely machined and have perfect alignment of the load. Also a longer specimen might concentrate the stress to produce one crack. A suggestion that might improve the measurements of crack length is to polish the sides of the specimens. This could eliminate the porous spots thus making the end point of the crack more obvious.

Load Vs Displacemnt plot for DCB test.



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1988 USAF-UES SUMMER COLLEGE RESEARCH PROGRAM

1988 COLLEGE SCIENCE AND ENGINEERING PROGRAM

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FINAL REPORT

Prepared by:	Anjanette Knappenberger
Academic Rank:	Sophomore
Department and	Astro/Aeronautical Engineering Department
University:	Purdue University
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USAF Researcher:	Capt. Ken Philippart Capt. Marlow Moser Capt. Joe Cor

Date:	19 Aug 88
Contract No.:	F49620-88-C-0053

Development of Solid Performance Program and Expert System Analysis

by

Anjanette Knappenberger

ABSTRACT

My work at the Air Force Astronautics Laboratory involved three major projects. The first project, which became the most time consuming, was the Solid Performance Program. The program is very powerful and the most accurate of anything of its kind, but can also be very confusing to learn to use efficiently. During my work at AFAL, a few of the problems have been solved making it slightly easier to use.

My second project with AFAL also involved computers but in a different manner. Greg Hall and I researched many aspects of expert systems. Although we recommended not purchasing an expert system shell at this time, the benefits in the future may outweigh some of the problems.

The rest of my time at AFAL was spend in the Combustion Laboratory. The main project I worked on was a plasma chamber, but one of the others was a vacuum chamber. Most of my tasks in the Combustion Lab were technical jobs.

I. INTRODUCTION:

As a sophomore in Astro/Aeronautical Engineering at Purdue University and through the experience of a previous job as a computer programmer, I have had much practice in dealing with both computer hardware and software. With this working knowledge, I became a prime candidate to work with the Solid Performance Program (SPP). SPP is a large fortran computer program made up of several hundred modules. SPP calculates the theoretical and the predicted delivered Isp and prints an extensive listing of every percent of the Isp that is lost. Working with this newly updated version 6.0 required a knowledge of fortran and a great deal of patience and effort.

Also to enhance my software interest, Greg Hall, another summer fellow, and I were given the task of researching Artificial Intelligence with concentration on Expert Systems. Our section may consider purchasing an expert system shell for propellant formulation design. Basically the assignment was to familiarize myself with Expert Systems and be able to rate some of the systems available.

Finally my desire for technical experience along with the lack of personnel in the Combustion Laboratory enabled me to work many hours of on the job training as a lab technician.

II. OBJECTIVES OF THE RESEARCH EFFORT

Before arriving at the Air Force Astronautics Laboratory, I was unsure of my goals and responsibilities. After a few days, my main goal was to familiarize myself with the SPP program. Eventually this would lead into running the program many times with different kinds of data to search for any problems in the code, or to help to develop any tricks into entering the data in the highly structured manner.

After working at the Astronautics Lab several weeks, another task was added to my responsibilities. This task, given to Greg Hall and me, was to research and learn about Expert Systems. Greg Hall and I formed our ideas through many tests and magazine articles. The final effort of this this assignment was to discuss the possibility of obtaining an expert system to aid in propellant formulation with our Section Chief, Dr. Kessel; and our Branch Chief, Dr. Quinn. Then finally discuss this possibility with Software Engineers and Associates (SEA).

My final responsibility was to the Combustion Lab. My duties and goals would change daily solely dependent on which of the lab projects I was working on that particular day. One special goal was to locate and fix any pressure leaks on a plasma chamber that was being built.

The gas control system, a major part of the controls to the plasma chamber, was another of my responsibilities in the lab. My task was to design, build, and test that portion of the control system.

III.

a. Before I could begin working with the Solid Performance Program, I first had to learn quite a bit more about solid rockets, their performance, their problems, and their advantages. I had to learn what Isp is, how to calculate Isp, and relative values for solid rockets both in the atmosphere and in a vacuum. The background information in itself was quite a task.

After gaining some background information on solid rockets and their performance, learning the data format had to be mastered. To aid in this task was the preprocessor of SPP. I went through the preprocessor a few times, only to discover how many variables a program of this magnitude contains. After several tries, I could create a data file for SPP and by altering this file, adding to the file, and combining it with existing libraries of code, I could test several different combinations of solid rockets.

My efforts toward my other task of researching expert systems was started by a meeting between Greg Hall and me. We soon realized that neither of us had a background in artificial intelligence and even less in expert systems. We began our efforts together and spent the next several days in the libraries on base and at AFAL. Our spare time was spend reading texts and following examples of expert systems. We held several discussions in order to check each other's understanding.

My efforts in the Combustion Lab seemed slow and uncoordinated at first. Most of the work I did was technical and much of it had to be explained before I could proceed. But with experience, I gained confidence and control. My final efforts in the lab saw the start through completion of a completely independent effort toward the gas control system.

b. My efforts with SPP resulted in two major accomplishments. The first achievement was sparked by the fact that the preprocessor of SPP would not help a beginner to learn the variables or what they represented in an actual solid rocket motor. The preprocessor didn't prove itself to be an efficient way to develop a working data file. Through the work I did, I felt that only practice

with altering an existing data file could properly reveal the representation of the variables. An effort was started to change the code of the preprocessor in order to make it both easier to use and more beneficial to future users.

The final pedicted Isp, calculated by SPP, of several solid rocket motors and their deviations from the actual Isp from fired rocket motors were plotted.

The other major achievement was the discovery of an error in the program that was never noticed in previous runs. After several examples of faulty results, Software Engineers and Associates, the developers of the code, recognized and corrected the error.

The result of the research of expert systems between Greg Hall and me was the conclusion that considering the time factor to develop the system and the high cost of an effective system, the program is too costly. The expense of an expert system plus the five man-years needed to start up the system do not, in our opinion, justify the few rewards the system offers.

The accomplishments in the lab are primarily shown in the development of the plasma chamber. The chamber was tested

in our lab up to sixty pounds per square inch. In the last few days of my work with AFAL, the plasma chamber was sent to be tested at a much higher pressure and temperature than allowable in our Combustion Laboratory. Unfortunately, I didn't have the opportunity to hear any more results of these final tests before my departure.

IV. RECOMMENDATIONS:

a. The suggestions I offered in the course of this research project have been implemented. The two problems found in SPP have been corrected, and thus far Greg Hall and I have met little opposition in our disapproval of expert systems.

b. Although none of the Air Force Astronautics Laboratory research concerning expert systems will be done by Greg Hall or me, we both feel that an expert system may be a better investment in the future when both the cost and the time required are reduced. The other projects I was involved with will be continued at the Astronautics Laboratory in my absence.

Acknowledgements

I would like to take this opportunity to thank the Air Force Astronautics Laboratory, the Aerothermochemistry Section and the Combustion Laboratory, the Air Force Systems Command, and the Air Force Office of Scientific Research for their sponsorship of this program. I also wish to thank Universal Energy Systems for extending this valuable opportunity to me.

I would like to extend my gratitude to several of my co-workers who each in their way helped to make this a rewarding and enriching experience. Dr. Phil Kessel was truly helpful in introducing me to the work and projects of this section. Dr. Larry Quinn's concern and appreciation was very encouraging. I would like to thank Capt. Marlow Moser and Capt. Ken Philippart for all their suggestions in learning SPP and especially for the comic relief they provided. Elizabeth Slimak provided me with support that was really appreciated in learning SPP. TSgt. Tracey Christensen was indispensable in teaching me many of the technical skills I learned. His patience never waivered. I would also like to thank Capt. Joe Cor for all his very fine suggestions and additions to the projects I was involved with.

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

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FINAL REPORT

An Interactive Frequency Analysis Program for Time Series

Prepared by: Liron Kronzon

Academic rank: Undergraduate student (Sophomore)

Department and University: Applied Mathematics Department, Yale University

Research Location: AFAL/SCS
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USAF Researcher: Dr. Tae-Woo Park

Date: 1 September 1988

Contract No: F49620-88-C-0053

An Interactive Frequency Analysis Program for Time Series

by

Liron Kronzon

ABSTRACT

An interactive, user-friendly FORTRAN program was developed in FORTRAN code for the purpose of performing a frequency analysis on time-series data obtained from solid motor rocket experiments. Processing the data involved determining the "zeroes" or level crossings for a given threshold level and identifying each extremum located between successive level crossings. Frequency analysis was achieved through Glassman's General N Fast Fourier Transform (FFT). User-program interaction allows the selection of subsets of the data for Forward or Inverse FFT with uniform or variable shifts and overlap/non-overlap processing. From the FFT results, the dominant frequency components in the data are identified, and the decay/growth rate for each of the dominant frequencies may be estimated. All results were stored in documented data-files compatible in format with MATRIX_X^{TM}, a computer-aided engineering application, to generate report-quality plots.

ACKNOWLEDGMENTS

I wish to thank the Air Force Systems Command and the Air Force Office of Scientific Research for their sponsorship of this program. Universal Energy Systems and AFAL/SCS in general, and Focal Point Coordinator Dick Clark in particular, deserve praise for their thorough guidance and support in all administrative and directional aspects of this program.

I wish to express my gratitude to the many individuals who contributed positively to my research efforts. Dr. Tae-Woo Park provided me with the necessary information, assistance and support, and made my experience as a Summer Fellow a truly pleasurable one. Dr. Yigal Kronzon's interest in the project from beginning to end was invaluable and greatly appreciated. Finally, Fellow researcher Johnson Earls' programming expertise saved the day on more than one occasion.

I. INTRODUCTION

One of the tasks performed by the Software and Analysis Section (SCS) at the Air Force Astronautics Laboratory (AFAL) at Edwards Air Force Base is the processing and analysis of experimental rocket combustion data. At present, the Section is particularly concerned with the development of programs to extract information pertaining to combustion instabilities that effect the operation of solid propellant rocket motors (reference 1).

My academic interests are in the combined fields of applied mathematics and computer science. The frequency anaylsis project presented a perfect opportunity to apply my knowledge in those fields. Moreover, my assignment in the AFAL/SCS allowed me to pursue related research within the context of aerospace engineering in a top-notch working environment.

II. OBJECTIVES OF THE RESEARCH EFFORT

My assignment as a Summer Fellow in the College Science and Engineering Program (CSEP) was to develop an interactive FORTRAN program to perform frequency analysis on oscillating time-series data. In

particular, the following information was to be computed and stored for further analysis:

1. The indexed time-series data vectors, if the original data was generated internally by a user-programmed function.
2. The indexed time-series data vectors, with the signal components of the vectors modified according to a user-specified threshold level.
3. The threshold level crossings (data points with a signal component identical to the specified threshold level) and the absolute extrema (data points with the highest or lowest signals) -- all indexed.
4. The Fast Fourier Transform results (see below) from the conversion of the data vectors from the time domain to the frequency domain.
5. The estimated value (Alpha) of the decay/growth rates of the oscillating signal data.

The program to compute this data was to be designed according to the following specifications:

1. It was to provide the user with a friendly, interactive environment.
2. It had be able to produce data-files compatible with the file format of MATRIX_X^{TM}, a computer-aided

engineering package capable of generating report-quality plots (*reference 6*).

III. PROGRAM STRUCTURE AND DESIGN

Note: The following is only a general description of the overall structure and function of the program. The program was written in American National Standard FORTRAN-77 (ANSI X3.9-1978) code. It was created on a Digital Equipment Corporation VAX-8650 / VMS V4 system (reference 5).

The design of the program incorporates modularization in order to achieve both simplicity of structure and maximum effectiveness during run time. Each distinct task is assigned to one or more separate modules for execution. This modular structure is implemented in the program by means of separate subprogram units known in FORTRAN as Entries and Subroutines (the names of these modules will be printed in boldface from here on).

An interactive environment was chosen for the program because it provided numerous advantages over the alternative, batch job processing. First, an interactive environment would provide the user with

maximum flexibility in specifying the required parameters for frequency analysis. Second, an interactive framework would allow him to control the flow of the analysis. Third, such a framework would present the user with opportunity to actively select among options, repeat others and manually specify the format of each data set and data file.

The interactive environment was also set to be as user-friendly as possible. An extremely useful feature of the program is the automatically updated display of upper and lower limits on all numerical selections. Another important feature are appropriate error-trapping routines and messages. In addition, the program permits regression to previous steps; notifies the user of all data-files being created; and provides default choices for nearly all options presented.

Finally, the program was designed so as to provide the user with the option of data-file compatibility with the $\text{MATRIX}_X{}^{TM}$ computer-aided engineering software. $\text{MATRIX}_X{}^{TM}$ is a powerful, programmable matrix calculator with built-in graphic capabilities (reference 6). By instructing the program to structure all data-files in the appropriate format, the user could take advantage of $\text{MATRIX}_X{}^{TM}$'s multitude of options, such as plotting any set of data. The graphs included in this report

were all generated by $MATRIX_X^{TM}$.

IV. DATA PROCESSING AND ANALYSIS

The initial step in the execution of the program is the introduction of a set of data points or vectors for analysis. The data set may be obtained from either real or simulated rocket motor combustion experiments. In both cases, it is assumed that the data vectors are generated at regular time intervals, so that each may be indexed and each has both time (t) and signal magnitude (s) coordinates.

In preparation for the frequency analysis and processing, a series of preliminary analytical operations is performed on the data set. The first of these operations is the modification of the signal itself for a given threshold level. The threshold level is a user-specified constant. The magnitude of the signal in each data vector is translated horizontally by this value so that the threshold level effectively becomes the "zero" axis for frequency analysis. The user may specify the mean signal value as the threshold level by default. The modified data vector is then indexed and stored in a separate data-file.

The next operation is the identification of the level-crossings. The level-crossings are the data vectors whose signal magnitude is identical to the threshold level. These vectors are essentially the "zeroes" of the time-dependent signal function. The program is set to determine the **approximate** level-crossings. It does so by comparing the signal amplitude of each pair of successive data vectors. If one signal value is below the threshold level and the other above it, then the closer of the two points is selected as the level crossing, indexed, and stored.

The program may also be set to determine the **exact** level-crossings by means of a triangulation algorithm. In essence, this algorithm creates a new data point with a signal value of zero by interpolating between two adjacent data points.

Once the level-crossings are identified, the absolute extrema (both absolute maxima and absolute minima) among the data vectors are isolated from the data set and stored separately in memory. The absolute extrema are the data points with the highest or lowest signal values between successive level crossings. The algorithm used to search for and recognize the absolute extrema is similar to the one employed to determine the

level-crossings. The signal values of data vectors in succession are compared, with the highest/lowest values stored in memory and on a data file, along with the level crossings previously identified.

At this point, the program is ready to perform its primary task, the frequency analysis of the time-series data. This analysis consists of two steps:

1. The Fast Fourier Transform of the oscillating time-series data in order to identify all mode frequencies of the rocket combustion motors.
2. Estimating Alpha, the constant rate of growth or decay for each of the frequencies of the oscillating signal.

V. THE FAST FOURIER TRANSFORM (FFT)

The oscillating time-series data to be analyzed is often extremely complex and may be composed of many dominant frequencies. It is therefore advantageous (and logical) to perform the analysis in the frequency domain. This approach allows for the simultaneous estimation of growth/decay rates for all dominant frequencies of interest, whereas filtering data vectors in the time domain would have required a series of pass

through the entire data set (see figure 1).

The transformation of time-series data from the time domain to the frequency domain is accomplished most effectively by the discrete Fourier transform. The Fast Fourier Transform (FFT) is one type of computer algorithm commonly in use that can rapidly perform the complex operations involved in the discrete Fourier transform (reference 2).

The particular FFT routine used in this program is known as 'Glassman's General N Fast Fourier Transform'. This FFT is based upon a representation of the discrete Fourier transform matrix as a product of sparse matrices (reference 3). The advantage of this FFT routine is that it can compute the discrete Fourier transform of data sets of arbitrary length. This is in sharp contrast to most other FFT routines (including MATRIX_X^{TM}'s own FFT), which require data sets to be of certain length, for example, a power of two. These routines pad Data sets with different lengths with additional zero vectors, thereby producing a distorted frequency spectrum.

The design of the FFT algorithm takes advantage of the program's interactive format. The program provides the user with the following options:

1. Performing Forward or Inverse Fourier transforms.
2. Selecting subsets of the data (or the entire data set) for frequency analysis. For example,

```
(Data-vector index line)

|----|----|----|----|----|----|----|----|----|----|----|--->
0    100  200  300  400  500  600  700  800  900  1000

|<------------------------------------------------->|
(1000-vector data set)

|<-->|                                    |<------->|
(100-vector data subset)        (200-vector data subset)
```

3. Choosing between overlap and non-overlap processing and choosing between uniform and variable shifts.

The user provides the index value of the first vector in the initial data subset. An arbitrary vector, a level crossing, or a an absolute maximum or minimum may be selected as the first data vector in the subset.

Data subsets must all be of a specified uniform length. Successive subsets may overlap (have certain data vectors in common) or may be non-overlapping (share no data vectors). The shifts (data vectors passed over

between initial vectors of successive data subsets) may be of a uniform (fixed) length or variable length. For example:

```
(Data-vector index line)

|----|----|----|----|----|----|----|----|----|----|--->
0   100  200  300  400  500  600  700  800  900  1000


|<---1--->|                  |<---1--->|
<US1>|<---2--->|             <VS1>|<---2--->|
     <US2>|<---3--->|             <..VS2..>|<---3--->|

(Overlap, Uniform Shifts)   (Overlap, Variable shifts)


|<---1--->|<.US1.>|<---2--->|<.US2.>|<---3--->|
(No overlap, Uniform Shifts)


|<-1->|<...VS1...>|<-2->|<..VS2..>|<-3->|
(No overlap, Variable Shifts)
```

VI. ESTIMATING GROWTH OR DECAY RATES

The final operation performed by the frequency analysis program is the computation of Alpha, the growth or decay rate of the oscillating time-series signal, for different frequencies (see figures 2 and 3). This

operation is composed of a series of steps. First, the dominant frequencies identified in each subset of the data are sorted by a QuickSort algorithm (see reference 4) according to their amplitude. The user then specifies the number of frequencies he is interested in for the Alpha estimate.

The program selects an equivalent number of frequencies having the highest amplitudes from the frequency spectrum of the first data subset. The amplitudes of the corresponding frequencies in the spectra of subsequent data sets are then searched for. In this fashion, a set of amplitudes is obtained for each frequency. The Alpha estimate for each frequency is then computed according to the formula:

LogE [ampX(frqZ) / ampY(frqZ)] / t(X)-t(Y) (1)
(X $\neq$ Y)

LogE = Natural Logarithm
frqZ = Zth Frequency
ampX(frqZ) = Xth amplitude of Zth frequency
ampY(frqZ) = Yth amplitude of Zth frequency
t(X) = Time value of 1st vector in Xth subset
t(Y) = Time value of 2nd vector in Yth subset

VII. RECOMMENDATIONS

The modular structure of the program lends itself easily to further expansion and improvement. Indeed, although the program presently performs a variety of analytical functions, it is far from being complete. Additional modules and routines may be easily incorporated into the program body to execute other important operations related to frequency analysis. One such useful routine might compute of the power spectrum from the FFT results. Another module could calculate the phase of each of the Fourier results. Yet a third could generate a waterfall plot of the results. The possibilities for additional modules are unlimited.

A different approach to modifying the program might be to incorporate it into the $MATRIX_X{}^{TM}$ package. With a few alterations, the program could be converted to a user-defined $MATRIX_X{}^{TM}$ function which could then be activated by an executable $MATRIX_X{}^{TM}$ file. Some of the modules in the program, such as the FFT routine, might even be substituted for $MATRIX_X{}^{TM}$'s own, less accurate functions.

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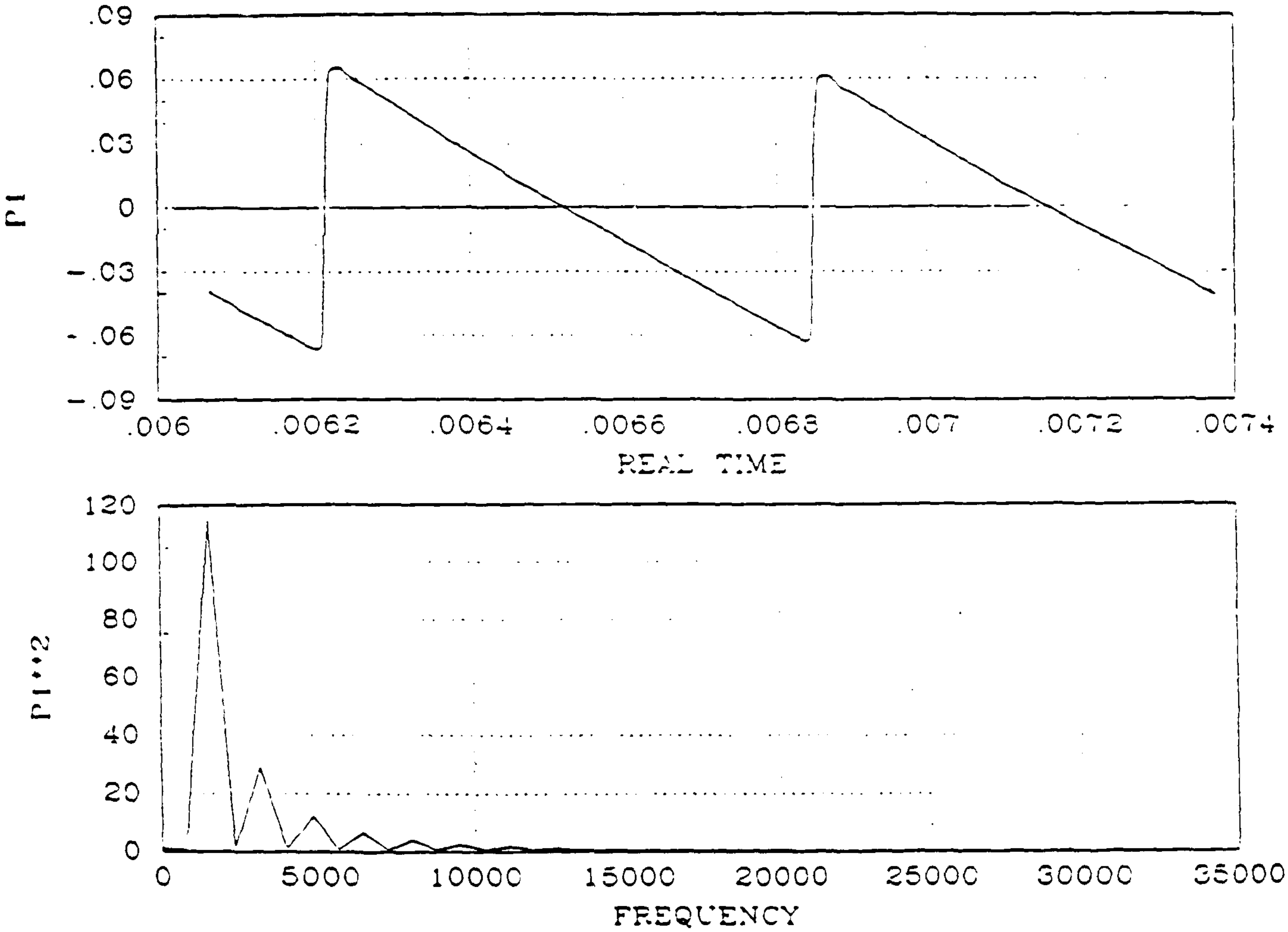
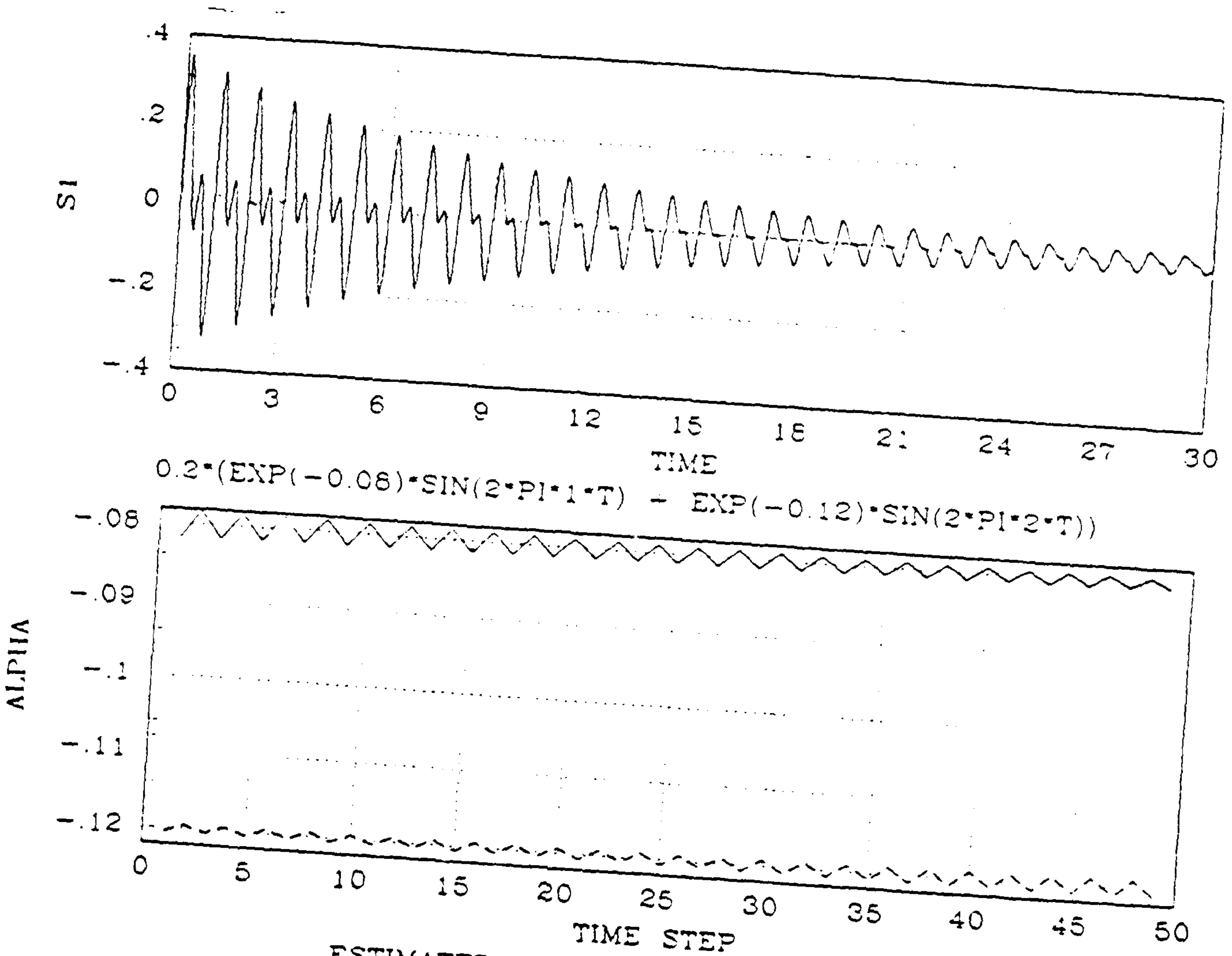


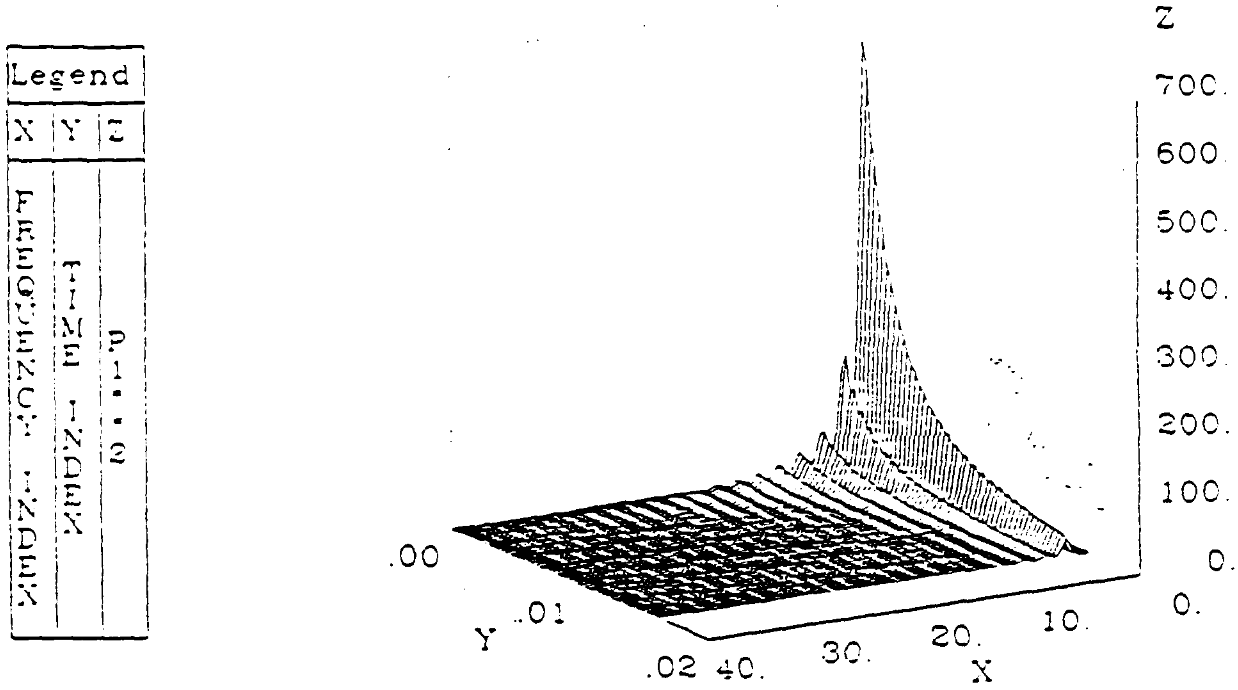
D00 A00 F05 AM20 P5 - 10, 11

Figure 1 shows the Fourier spectral analysis results (lower plot) for the 10th and 11th cycles of an oscillating pressure signal obtained by experiment (upper plot) (reference 1).



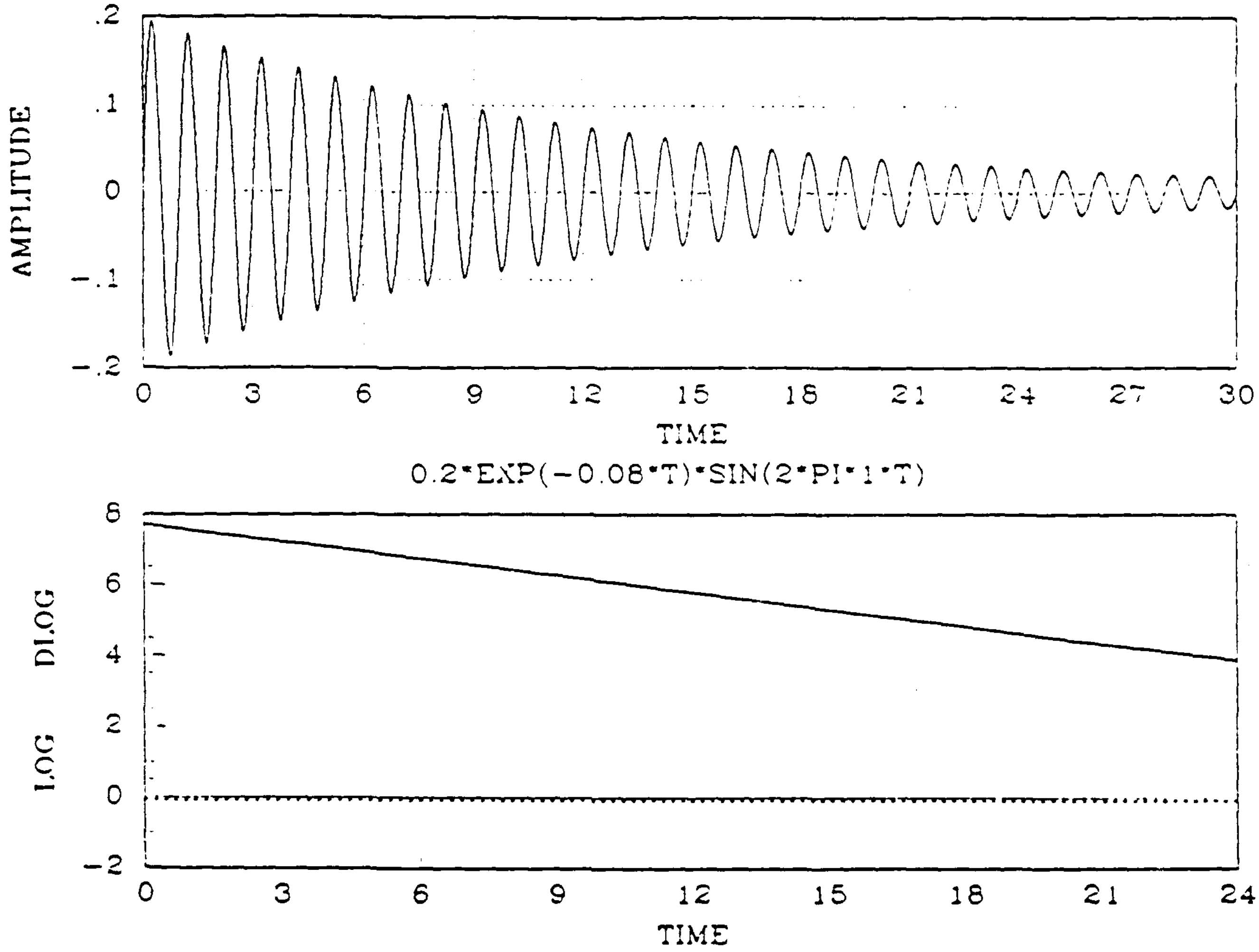
ESTIMATED ALPHA FROM SPECTRA

Figure 2 shows che time / signal data of a traveling sinusoidal function having two frequencies, 1hz and 2hz (upper plot). The estimated decay rate for each of these frequencies (-0.08 and -0.12, respectively) is the mean value of each Alpha curve (lower plot).



DOO AOO F05 AM20 P5 - 512 POINTS ENERGY SPECTRUM

Figure 3 is a [illegible] dimensional "waterfall" plot of the oscillating signal depicted in figure 1. The plot clearly displays the decay rate of the signal at each frequency over time.



DECAY RATE FROM SPECTRA OF DECAYING SINUSOID

Figure 4 shows a decaying sinusoidal wave with a frequency of 1hz and decay rate of -0.08 (upper plot). This decay rate is illustrated in the lower plot as both a constant (dashed line) and as a function of time (downward-sloping curve).

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FINAL REPORT

Nuclear Propulsion Modeling

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Research Location:	Air Force Astronautics Laboratory Astronautical Sciences Division Advanced Concepts Branch
USAF Researcher:	Lt. Ryan Haaland
Date:	30 Aug 1988
Contract No:	F49620-88-C-0053

Nuclear Propulsion Modeling

by

Andrew S. Martin

ABSTRACT

Nuclear propulsion was a concept that was extensively researched during the fifties and sixties. A recent effort has been underway to recover the technology that has lain dormant for the last fifteen years. My attempt is to survey the computer modeling capability available for evaluating the performance of nuclear propulsion concepts. Additional effort was expended in documentating and updating those codes in need of it. The models were then evaluated in terms of their applicability and usefulness to the current concepts being considered.

Acknowledgments

I would like to thank the Air Force Systems Command and the Air Force Office of Scientific Research for their sponsorship of my research via the College Science and Engineering Program. Additional thanks go to Universal Energy Systems under whose administration the program has flourished.

For the direction and purposes of my research I am indebted to Lt Ryan Haaland and Mr. Al Beale. These two individuals saw the need for this project and encouraged me to pursue it, while providing me with the background information necessary for my understanding. I also owe thanks to Mr. Warren Madsen of Idaho National Engineering Laboratories for the time and effort he expended in helping me to understand and update two of the modeling codes (NETAP and MINERVA).

I. INTRODUCTION:

Nuclear Propulsion as a concept is as old or older than the nuclear warhead. Even as the first ICBM's were being built, scientists were contemplating rockets propelied by heating low molecular weight propellants using nuclear fission reactors instead of combustion. These ideas were proposed, developed, and eventually resulted in the NERVA (Nuclear Engine for Rocket Vehicle Applications) engine, the last in a series of nuclear rocket and engine test units. This engine was successfully tested (including multiple starts, restarts, shutdowns, full-power runs, idling, etc.) on the ground using liquid hydrogen as the propellant. Unfortunately, the nuclear propulsion concept was abandoned in favor of chemical rockets in the early seventies. Not until recently has the need for the very high efficiency attainable from nuclear propulsion brought this concept under renewed scrutiny. The intervening time period has brought forward a new generation of micro and mini computers which have great potential for conducting much of the basic concept and design evaluation without the risks associated with any rocket motor firing.

II. OBJECTIVES OF THE RESEARCH EFFORT:

The major goal behind this effort is an identification of the computer codes currently available to assist in the evaluation and design of nuclear propulsion concepts. In addition to identifying these concepts an attempt was made to evaluate the strengths and weaknesses of each program and relay this information as well as pertinent operational information to the user of these programs.

III.

a. The first step in the previously described goals was to acquire any programs that might fit the criteria. Two of these programs (AFAL ISP and NETAP) were already in the possession of my Air Force mentor (Lt. Haaland), while the third program (MINERVA) was suggested by Warren Madsen of INEL while discussing features of the NETAP program. The last of these programs (ISPEAK) was written by another CSEP student this summer at the AFAL. The second step was to correct any problems in program compilation or execution. On several of the programs extensive debugging was required. The final step was to evaluate the programs with respect to the field of interest and report on their strengths and weaknesses.

b. The four evaluated programs are as follows: NETAP, MINERVA, AFAL ISP, and ISPEAK.

1. <u>NETAP</u>

NETAP (Nuclear Engine Transient Analysis Program) was written by R. Stiger, W. Madsen, R. Baisniki, J. Hudson, and R.A. Wells for use in analyzing the flows and heating in a NERVA-type engine prior to the actual ground test. This program is written in such a way that the user can specify the design parameters of the engine to be tested, the control system parameters, and the time frame to be shown. The program will then calculate the specific impulse, thrust, temperatures throughout the engine, flow rates through the different engine components, and heat flow through various parts. According to the people involved at the time of the NERVA tests, the program performed very well, predicting several phenomena that were ignored as program transients until they showed up in the actual tests. Unfortunately, the

most current documentation for this program is dated June 1972 and several undocumented (though minor) changes have been made to the program. This program could be very useful in providing a simulated testbed for nuclear engines, but the degree of detail in this program requires a complete design be used for evaluation, not just a general concept. As such, this program has little usefulness until an actual nuclear rocket is designed and ready to be tested.

2. MINERVA

MINERVA (Mission Integrated Nuclear Engine and Rocket Vehicle Analysis) was written by Mr. Warren Madsen of INEL. This program was written to perform a complete mission oriented analysis using a much simpler model then the NETAP program previously discussed. The user of this program need only know the design constraints of chamber temperature & pressure, nozzle area ratio, engine thrust or throat diameter, burn time, and startup time. This program will then proceed to simulate the complete cycle of a nuclear rocket, going through chill down, startup, full power burn, shutdown, and pulse cooling. The program keeps track of the propellant used during each stage of the cycle and reports back the design parameters as well as a complete report on the propellant used and the average specific impulse and thrust. This program has no documentation as it was written for in-house use by it's author. Fortunately, the program prompts the user for all inputs and is fairly specific as to format and units. There were several bugs which the author failed to catch in the execution of the program which resulted in distortion of the output values. After several consultations, we were able to trace down the problems and

correct them. This program is currently the most useful of the programs that I worked on due to it's mission oriented approach and lack of engine detail.

3. AFAL Isp

The Air Force Astronautics Laboratory isp program was originally written by Curtis Selph and Robert Hall while the microcomputer version was written by Charles Beckman and Robert Acree. This program is designed to evaluate the specific impulse and other variables for a point heat source rocket (nuclear, chemical, solids, etc.) using different combinations of propellants. While this program has the most complete gas properties section, enabling it to analyze different propellants, it lacks the startup and shutdown procedures of MINERVA which are needed to provide an accurate idea of the actual propellant mass that would be used on a mission. This code is well suited for analyzing the effect different propellants would have on the efficiency and usefulness of any rocket, but for more accurate representations of fuel quantities and specific impulse MINERVA should be used.

4. ISPEAK

ISPEAK is an editor for the input file for the AFAL Isp program. This program was written by another CSEP student, Kenneth Chew, to provide a much more user oriented interface to the AFAL Isp program. Though it does not pertain to nuclear propulsion modeling directly, I included it since I was evaluating the AFAL Isp program. I debugged and tested this program as of this report the program is completely functional. For any users of the AFAL Isp program on microcomputers, this program will significantly reduce the time required for data entry by automatically taking care of all of the formatting.

VII. RECOMMENDATIONS

a. These programs and their documentation are ready for use in performing analyses of nuclear propulsion technology. MINERVA can be used to provide estimates of complete nuclear engine operation for comparing costs and payloads to other vehicle systems, while AFAL isp serves as a good base from which to confirm the figures prepared by MINERVA. As mentioned previously, NETAP does not have any current applications, but is ready to perform the design confirmations of specific designs that are presented.

b. Both NETAP and MINERVA have one major constraint, hydrogen as the propellant. With the current trend away from cryogenics, both of these programs should me modified to incorporate different gases. Warren Madsen of INEL is interested in performing the modifications if someone is interested enough in seeing these modifications performed to fund it. Additionally, both programs need to be updated to reflect advances in materials technology.

c. A program that would be of the most use currently is a modified version of MINERVA that provided for evaluating the several different nuclear rocket concepts that have been proposed. Ideally the user could select which model was desired and the appropriate code for that model would be loaded.

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FINAL REPORT

CREATING A PREPROCESSOR AND EDITOR FOR ASTRONAUTICS LAB'S ISP PROGRAM

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Date:	1 September 1988
Contract No.	F49620-88-C-0053

Building a Preprocessor and an Editor for the AFAL ISP Program

by

Francis G. McDougall

ABSTRACT

In the RKLC section (Liquid Rocket section) of the Astronautics lab, I was working with my mentor, Curtiss Selph in creating a preprocessor and an editor for the ISP (rocket impulse) program he had developed earlier. The purpose of the preprocessor is to create a file from scratch that will interact with the main program. After interacting with the main, the main program will give useful information about the impulse of several chemical propellants. The editor I created is very useful for taking a previous file store in a data location in memory and changing it either moderately or radically. So this editor can act as a quick preprocessor to a user that is familiar with ISP main program. More important, though, is the time it saves the user from editing a file using the editor that runs on the disk operating system.

Acknowledgements

I wish to thank the Air Force System Command and the Air Force Office of Scientific Research for sponsorship of this undergraduate research.

As a physics major, the work I accomplished in computer programming will help me in applied physics, especially in scientific instrumentation. Universal Energy Systems must be mentioned for their concern and help to me in all administrative and directional aspects of this program.

My work that I accomplished would not have been possible if it were not the help of Curtiss Selph and Thomas Elkins. They both helped in computability of the Fortran code I used. I also like to thank the RKLC section chief, Bernard Bohrnhorst, for his assistance whenever I needed computer hardware or software. I also like to thank Ann Krach. She provided me with all the information of this UES position while I was still attending spring semester at California State University Dominguez Hills. Further, I like to mention it was an enjoyable experience working with David Armbruster, Robert Drake, and Judy Pletsch, another undergraduate UES student. Of course, it was also a pleasure working for the people I just mentioned who assisted me. Last, I also like to mentioned that the UES area contact, Richard Clark and Wayne Roe were personally helpful in the administrative,and directional aspects of this program.

I must also express my admiration of the entire complex of the Astronautics Laboratory, located at Edwards Air Force Base. I think that they are the forefront of modern technology.

I. Introduction:

Among the many analytical tools employed by the AFAL is a program for calculating theoretically the parameter specific impulse, or ISP. ISP is the impulse (in pound of force times seconds of operation) divided by the mass of propellant. The ISP program is a mature code developed many years ago on a main frame computer prior to the advent of microcomputers or interactive terminals. Input to the program took the form of batch file. Recently the program was converted to run on the Zenith Z-100 microcomputer and also the Z-248, which is IBM compatible. However, it kept the same batch file input, requiring familiarity on the part of the user with the input format. A more user-friendly environment is possible in the micro environment with on-screen menus, helps keys and input prompts. The development of a pre-processor to interface with the ISP code was given to me as my task.

So for the 55 days approved for my contract, I would relearn how to program in Fortran. I had taken a Fortran course 6 years ago, so I had retained the rudimentary skills of this language. After this, I started on the preprocessor. Finally, I worked on the editor. All during this time I learned several things about rocket design, programming and scientific procedures and methods in an engineering environment.

II. OBJECTIVES:

It was during the first week that my USAF Research mentor, Curtiss Selph, gave me suggestions how he wanted the preprocessor to function and he explained how he wanted the editor to work. I took all of his advice and began to work on this project. So the preprocessor had to open a data tape file as a new file for fresh data. It is up to the user to provide this data. As he is asked several questions from my preprocessor, he provides specific answers. These answers are the stored in specific addresses and the data tape is closed. It is reopened by the main program, data is then retrieved and processed by the main impulse program of the ISP program. An adequate postprocessor then post the resuilts of the run.

The length of the preprocessor grew quite large and cumbersome. It takes several minutes to run the preprocessor. So by my eighth week of work, Mr. Selph suggested that I work on the editor solely. I agreed and told him that I will complete my preprocessor during winter break from college. This will enable me to receive more cooperative education units from my campus for doing additional work on this task. The editor was so much easier to create and have the user implement on his run of the ISP codes. It is so much more convienent to have an editor built into the program. That was a major objective. One no longer has to create a data on an outside the program. He can stay within the program for the duration of his tasks. Indeed, this is possible because the editor is linked within the program.

III.

a. The approaches I had taken were simple. If I ran into a problem, I would look into either a Fortran textbook or the Zenith softhware documentation of their version of Fortran. I was assigned the task of making all the codes I created to be compatible with the Zenith Z-100 desktop computer. So the objectives I mentioned were met.

b. Here is a display of a typical run of ISP, after implementing my editor.

```
E> INPUT.DAT
ELM
    X        1.008
    Y        2.014
MOD
    N1.       X3.                                      20         2-.3580   61.446      NX3
   16.5432 31.0753 -107.736123.2698-50.5731
   8.2485  -5.9685 31.411   -29.5    9.2934
    N1.      Y3.                                       20         2-1.993   66.066      NY3
   16.6204 29.9464 -94.3748106.9347-44.6819
   7.9696  -4.0698 37.5583 -38.971412.8056
    N1.      D3.
    N1.      H3.
LIB
   N2H4      12.05     1.004      N2.       H4.
   N2D4      3.07      1.13       N2.       D4.
   N2X4      12.05     1.004      N2.       X4.
   N2Y4      3.07      1.13       N2.       Y4.
   N2D4      12.05     1.13       N2.       D4.
   N2Y4      12.05     1.13       N2.       Y4.
CHP
   1000.
EXP
   14.7
NTH
SEL
             3
             1
WTS
    .10      .9
    .2       .8
    .3       .7
    .4       .6
    .5       .5
    .6       .4
    .7       .3
    .8       .2
    .9       .1
XEQ
END

E>
```

```
  AFAL SPECIFIC IMPULSE PROGRAM
     by CURTIS C. SELPH
ELM
    X          1.0080
    Y          2.0140
MOD
     N     1.  X    3.        0.        0.  0     20        2       0.       61.   NX3
     N     1.  Y    3.        0.        0.  0     20        2      -2.       66.   NY3
     N     1.  D    3.        0.        0.  0      0        0       0.        0.
     N     1.  H    3.        0.        0.  0      0        0       0.        0.
LIB
N2H4                12.0500     1.0040
 N    2.0000   H     4.0000
N2D4                 3.0700     1.1300
 N    2.0000   D     4.0000
N2X4                12.0500     1.0040
 N    2.0000   X     4.0000
N2Y4                 3.0700     1.1300
 N    2.0000   Y     4.0000
N2D4                12.0500     1.1300
 N    2.0000   D     4.0000
N2Y4                12.0500     1.1300
 N    2.0000   Y     4.0000
```

```
     1000.000
:XP
        14.700
:TH
:EL
          3
          1
:TS
          .100     .900     .000     .000     .000     .000     .000     .000     .000
          .200     .800     .000     .000     .000     .000     .000     .000     .000
          .300     .700     .000     .000     .000     .000     .000     .000     .000
          .400     .600     .000     .000     .000     .000     .000     .000     .000
          .500     .500     .000     .000     .000     .000     .000     .000     .000
          .600     .400     .000     .000     .000     .000     .000     .000     .000
          .700     .300     .000     .000     .000     .000     .000     .000     .000
          .800     .200     .000     .000     .000     .000     .000     .000     .000
          .900     .100     .000     .000     .000     .000     .000     .000     .000
:ED
H       H2       HN       H2N      H2N2     H3N      H4N2     N        N2
N3      ZN+      H4N2(L   PROPELLANT      HF      DENSITY     WEIGHT   MOLES          VOLUME)
N2X4               12.0500    1.0040     .1000      .0031      .0996
N2H4               12.0500    1.0040     .9000      .0281      .8964

 GRAM ATOMS  /100 GRAMS
 H  11.2341   N   6.2412   X   1.2482

ENTHALPY =   37.60303              DENSITY =1.004
 PRESSURE (PSIA)             1000.000        14.700
 EPSILON                         .000          .000
 ISP                             .000       191.844
 ISP (VACUUM)                    .000       203.756
 TEMPERATURE(K)               944.549       295.481
 MOLECULAR WEIGHT              11.179        11.179
 MOLES GAS/100G                 8.946         8.946
 CF                              .000          .000
 PEAE/M (SECONDS)                .000        11.912
 GAMMA                          1.352         1.401
 HEAT CAP (CAL)                68.247        62.105
 ENTROPY (CAL)                341.567       341.572
 ENTHALPY (KCAL)               37.603        -4.677
 DENSITY (G/CC0           9.81405E-03   4.61170E-04
 ITERATIONS                        20             4

H2                            5.61705       5.61705
N2                            2.91254       2.91254
  NX3                          .41608        .41608
 PROPELLANT      HF      DENSITY     WEIGHT   MOLES             VOLUME)
N2X4             12.0500    1.0040     .2000      .0062      .1992
N2H4             12.0500    1.0040     .8000      .0250      .7968

 GRAM ATOMS  /100 GRAMS
 H   9.9859   N   6.2412   X   2.4965

ENTHALPY =   37.60301              DENSITY =1.004
 PRESSURE (PSIA)             1000.000        14.700
 EPSILON                         .000          .000
 ISP                             .000       196.953
 ISP (VACUUM)                    .000       209.438
 TEMPERATURE(K)              1024.417       333.427
 MOLECULAR WEIGHT              11.724        11.724
 MOLES GAS/100G                 8.530         8.530
 CF                              .000          .000
 PEAE/M (SECONDS)                .000        12.484
 GAMMA                          1.328         1.391
 HEAT CAP (CAL)                68.596        60.347
```

```
ENTHALPY (KCAL)              37.603          -6.959
DENSITY (G/CC0          9.49029E-03     4.28622E-04
ITERATIONS                        3               5

H2                          4.99293         4.99294
N2                          2.70451         2.70450
 NX3                         .83215          .83215
PROPELLANT    HF      DENSITY    WEIGHT   MOLES                  VOLUME)
N2X4            12.0500    1.0040      .3000       .0094      .2988
N2H4            12.0500    1.0040      .7000       .0218      .6972

GRAM ATOMS  /100 GRAMS
H    8.7376   N    6.2412   X    3.7447

ENTHALPY =   37.60300              DENSITY =1.004
PRESSURE (PSIA)            1000.000          14.700
EPSILON                        .000            .000
ISP                            .000         201.595
ISP (VACUUM)                   .000         214.693
TEMPERATURE(K)             1104.245         376.431
MOLECULAR WEIGHT             12.325          12.325
MOLES GAS/100G                8.114           8.114
CF                             .000            .000
PEAE/M (SECONDS)               .000          13.098
GAMMA                         1.303           1.377
HEAT CAP (CAL)               69.262          56.846
ENTROPY (CAL)               337.654         337.654
ENTHALPY (KCAL)              37.603          -9.084
DENSITY (G/CC0          9.25573E-03     3.99124E-04
ITERATIONS                        3               4

H2                          4.36882         4.36882
N2                          2.49647         2.49647
 NX3                        1.24823         1.24823
PROPELLANT    HF      DENSITY    WEIGHT   MOLES                  VOLUME)
N2X4            12.0500    1.0040      .4000       .0125      .3984
N2H4            12.0500    1.0040      .6000       .0187      .5976

GRAM ATOMS  /100 GRAMS
H    7.4894   N    6.2412   X    4.9929

ENTHALPY =   37.60299              DENSITY =1.004
PRESSURE (PSIA)            1000.000          14.700
EPSILON                        .000            .000
ISP                            .000         205.723
ISP (VACUUM)                   .000         219.481
TEMPERATURE(K)             1183.530         425.303
MOLECULAR WEIGHT             12.991          12.991
MOLES GAS/100G                7.697           7.697
CF                             .000            .000
PEAE/M (SECONDS)               .000          13.758
GAMMA                         1.278           1.361
HEAT CAP (CAL)               70.260          57.684
ENTROPY (CAL)               334.386         334.387
ENTHALPY (KCAL)              37.603         -11.015
DENSITY (G/CC0          9.10248E-03     3.72356E-04
ITERATIONS                        3               5

H2                          3.74470         3.74470
N2                          2.28843         2.28843
 NX3                        1.66430         1.66431
PROPELLANT    HF      DENSITY    WEIGHT   MOLES                  VOLUME)
N2X4            12.0500    1.0040      .5000       .0156      .4980
N2H4            12.0500    1.0040      .5000       .0156      .4980
-----------------------------------
```

H 6.2412 N 6.2412 X 6.2411

ENTHALPY = 37.60297		DENSITY =1.004
PRESSURE (PSIA)	1000.000	14.700
EPSILON	.000	.000
ISP	.000	209.283
ISP (VACUUM)	.000	223.744
TEMPERATURE(K)	1261.995	480.769
MOLECULAR WEIGHT	13.734	13.734
MOLES GAS/100G	7.281	7.281
CF	.000	.000
PEAE/M (SECONDS)	.000	14.462
GAMMA	1.255	1.341
HEAT CAP (CAL)	71.207	56.935
ENTROPY (CAL)	330.395	330.396
ENTHALPY (KCAL)	37.603	-12.712
DENSITY (G/CC0	9.02434E-03	3.48220E-04
ITERATIONS	7	6

H2	3.12058	3.12058
N2	2.08038	2.08039
NX3	2.08038	2.08039

PROPELLANT	HF	DENSITY	WEIGHT	MOLES		VOLUME)
N2X4		12.0500	1.0040	.6000	.0187	.5976
N2H4		12.0500	1.0040	.4000	.0125	.3984

GRAM ATOMS /100 GRAMS
H 4.9929 N 6.2412 X 7.4894

ENTHALPY = 37.60296		DENSITY =1.004
PRESSURE (PSIA)	1000.000	14.700
EPSILON	.000	.000
ISP	.000	212.205
ISP (VACUUM)	.000	227.406
TEMPERATURE(K)	1339.486	543.478
MOLECULAR WEIGHT	14.566	14.566
MOLES GAS/100G	6.865	6.865
CF	.000	.000
PEAE/M (SECONDS)	.000	15.201
GAMMA	1.233	1.317
HEAT CAP (CAL)	72.303	56.686
ENTROPY (CAL)	325.723	325.723
ENTHALPY (KCAL)	37.603	-14.127
DENSITY (G/CC0	9.01756E-03	3.26711E-04
ITERATIONS	7	6

H2	2.49647	2.49647
N2	1.87235	1.87234
NX3	2.49646	2.49646

PROPELLANT	HF	DENSITY	WEIGHT	MOLES		VOLUME)
N2X4		12.0500	1.0040	.7000	.0218	.6972
N2H4		12.0500	1.0040	.3000	.0094	.2988

GRAM ATOMS /100 GRAMS
H 3.7447 N 6.2412 X 6.7376

ENTHALPY = 37.60295		DENSITY =1.004
PRESSURE (PSIA)	1000.000	14.700
EPSILON	.000	.000
ISP	.000	214.417
ISP (VACUUM)	.000	230.378
TEMPERATURE(K)	1415.848	613.762
MOLECULAR WEIGHT	15.506	15.506
MOLES GAS/100G	6.449	6.449
CF	.000	.000

GAMMA	1.211	1.290
HEAT CAP (CAL)	73.440	56.981
ENTROPY (CAL)	320.362	320.363
ENTHALPY (KCAL)	37.603	-15.212
DENSITY (G/CC0	9.08161E-03	3.07962E-04
ITERATIONS	7	6

H2	1.87235	1.87235
N2	1.66430	1.66432
NX3	2.91253	2.91253

PROPELLANT	HF	DENSITY	WEIGHT	MOLES	VOLUME)
N2X4	12.0500	1.0040	.8000	.0250	.7968
N2H4	12.0500	1.0040	.2000	.0062	.1992

GRAM ATOMS /100 GRAMS
H 2.4965 N 6.2412 X 9.9858

ENTHALPY = 37.60293 DENSITY =1.004

PRESSURE (PSIA)	1000.000	14.700
EPSILON	.000	.000
ISP	.000	215.839
ISP (VACUUM)	.000	232.556
TEMPERATURE(K)	1491.014	691.761
MOLECULAR WEIGHT	16.575	16.575
MOLES GAS/100G	6.033	6.033
CF	.000	.000
PEAE/M (SECONDS)	.000	16.717
GAMMA	1.192	1.262
HEAT CAP (CAL)	74.594	57.821
ENTROPY (CAL)	314.254	314.254
ENTHALPY (KCAL)	37.603	-15.914
DENSITY (G/CC0	9.21855E-03	2.92082E-04
ITERATIONS	7	6

H	.00001	.00000
H2	1.24823	1.24823
N2	1.45627	1.45627
NX3	3.32861	3.32861

PROPELLANT	HF	DENSITY	WEIGHT	MOLES	VOLUME)
N2X4	12.0500	1.0040	.9000	.0281	.8964
N2H4	12.0500	1.0040	.1000	.0031	.0996

GRAM ATOMS /100 GRAMS
H 1.2482 N 6.2411 X 11.2341

ENTHALPY = 37.60292 DENSITY =1.004

PRESSURE (PSIA)	1000.000	14.700
EPSILON	.000	.000
ISP	.000	216.391
ISP (VACUUM)	.000	233.833
TEMPERATURE(K)	1564.959	777.218
MOLECULAR WEIGHT	17.803	17.803
MOLES GAS/100G	5.617	5.617
CF	.000	.000
PEAE/M (SECONDS)	.000	17.443
GAMMA	1.173	1.233
HEAT CAP (CAL)	75.756	59.150
ENTROPY (CAL)	307.203	307.202
ENTHALPY (KCAL)	37.603	-16.188
DENSITY (G/CC0	9.43355E-03	2.79224E-04
ITERATIONS	7	6

H	.00001	.00000
H2	.62412	.62412
N2	1.24823	1.24823

NX3	3.74470	3.74469
END		

IV. RECOMENDATIONS:

The editor for the ISP codes is fully functional. It mimics most editors. It allows you to insert text, delete text, move up and down a file and move across text. As I said before, the editor can radically change the file so as to have a totally different file on hand. So the editor can function as a preprocessor to the experience user of the ISP operation codes. This may indeed be the case because my preprocessor is slow and cumbersome.

I will have to alter the coding for the preprocessor to run faster. As of now, for similar data input, I have the processor execute a loop. This loop may irritate the user because it asks the same question up to ten times. What I have to do, is to have the preprocessor create a field which will collect ten datum and aks only one question. This may seem like a task that can be handle in a few days, it is not. There are 66 different operations in the main ISP code. I have access to 37 operations with my preprocessor. I have created 34 procedures to send information to these operations. That means that have to access at least 34 loops and modify them. I plan to return several days out of my two weeks of Christmas break.

After the preprocessor is efficient, I see that I can further add to the ISP codes. First, I can add to the number of mathematical operations within the main program to further improve the accuracy of predicted ISP (rocket impulse) with actual impulse

from rocket test. I have signed up for a numerical analysis course at my campus, California State University Dominguez Hills. This will be of aid if I do implement additional math codes in the future to this program. Then I can implement a different postprocessor, so that when the ISP codes are linked to another program that does such things as stress analysis and design, it will further enhance that program with rocket impulse.

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FINAL REPORT

Regenative Cooling Limits of N2O4 & MMH for Upper Storable Rocket Engines.

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USAF Researcher:	Lt Jim Rymarcsuk
Date:	19 AUG 88
Contract No:	F49620-88-C-0053

ACKNOWLEDGMENTS

I wish to thank the Air Force Systems Command, the Air Force Office of Scientific Research and the Air Force Astronautics Labcratory for a rewarding and learning experience. My exposure to the work done at the lab was enriched because of the many different influences. Lt Jim Rymarcsuk has provided me with essential technical advice and a positively enjoyable working atmosphere. The help of Jim Nichols has also advanced me through numerous difficulties.

Regenative Cooling Limits of N2O4 & MMH for Upper Storable Rocket Engines.

by

Bruce Tuan Pham

ABSTRACT

Classically, fuel has been used as the regenerative cooling fluid due to its better heat transfer capabilities and chemical compatibility with metals. However, for low thrust and high chamber pressure engines such as the XLR-132, heat transfer loads become too large for standard fuel cooling techniques. Since these storable engines typically operate at oxidizer to fuel ratios of between 1.5 to 2.5, there is about twice as much oxidizer as fuel for cooling. Also, at high pressures (above 1470 psia) the oxidizer becomes super-critical and has improved heat transfer characteristics. Thus, oxidizer regenerative cooling becomes the better alternative for high pressure, low thrust storable engines. The purpose of this paper is to determine the thrust level and chamber pressure range were oxidizer or fuel cooling is most appropriate. The oxidizer used in this investigation is nitrogen tetraoxide (N2O4) and the fuel is monomethyl hydrazine (MMH).

I. INTRODUCTION

As the demand to place satellites in various orbits increases, the need for advancement in space propulsion is apparent. Advanced technology in space propulsion concepts are being developed by the Air Force Astronautics Laboratory. Currently, the Experimental Liquid Rocket Engine 132 (XLR-132) is in its second phase of development. The engine is to have 3750 lbf of thrust using the storable propellants nitrogen tetraoxide and monomethyl hydrazine (N2O4/MMH). With a specific impulse of 340 sec and an overall dimension of 2 feet in diameter and 4 feet long, the XLR-132 will be durable, easy to resupply, cost effective and will have broad applicability.

My interests have been in the area of gas dynamics and aerodynamics. Working with the XLR-132 has introduced me to a great deal of heat transfer concepts, which I found to be considerably interesting. My work on the XLR-132 has been to analyze the effects of coolant sizes, thrust levels, and the effect of different coolant properties (N2O4/MMH) have on temperature of the combustion chamber.

Due the insufficient amount of time, I was unable to complete this project. Therefore, I will only report what I have done so far.

II. OBJECTIVES OF THE RESEARCH EFFORT

Our approach is to develop a heat transfer model of a combustion chamber and coolant channels comparable to that of the XLR-132. In particular, the Two Dimensional Kinetics with Boundary Layer Module program (TDK/BLM) was used to determine the gas side, and a spread sheet program was used to calculate the coolant side heat fluxes. Validation of this model can be obtained by comparing the calculated heat transfer characteristics with test data from the XLR-132 engine. Then, the parameters of the model can be varied to determine the limiting heat transfer capabilities of the propellants. From this, the acceptable operating range for N2O4 and MMH as regenerative coolants can be found as a function of chamber pressure and thrust. With this data, one can readily determine the most appropriate coolant for a particular engine design. This information will be essential for performing the conceptual design of future upper stage storable rocket engines.

III. APPROACHES AND RESULTS

a. GATHERING DATA:

Critical properties of N2O4 and MMH were required to ensure that their conditions were not violated. Due to the high range of operating temperature (560 - 1100 degrees R), data for the propellants were difficult to find. Assuming a constant pressure, which is reasonable for the coolant chamber of the XLR-132, an interpolation program was used to relate functions of viscosity, specific heats, thermal conductivity, and density of propellants to temperatures. From reference 4, the critical properties of the propellants were found (table 1).

CRITICAL PROPERTIES

	N2O4	MMH
Freezing Point (F)	11.8	-62.5
Boiling Point (F)	70.1	192.0
Critical Pressure (psia)	1470	1195
Critical Temp (F)	317.0	594.0
Critical Density (lb/gal)	4.65	2.42

Table 1. Critical properties of N2O4 AND MMH.

b. BUILDING A HEAT TRANSFER MODEL:

A heat transfer model was constructed through the aid of Lotus 123. To form a reasonable configuration, the model was tailored closely to the shape of the XLR-132. All dimensions of the model are a function of the throat radius i.e., varying the radius of the throat will automatically change the chamber's radius, the exit nozzle's radius and the number of coolant channels. As an initial trial, constant slopes for the convergent and divergent nozzle were used to simplify the task. Other input parameters are coolant mass flow rate, chamber wall thickness, exit wall thickness, contraction ratio and the angle of the exit nozzle. Once the model is completed, at any incremental point along the combustion chamber, the coolant area (hydraulic diameter), chamber radius, contraction ratio, and the wall thickness can be found. Refer to figure 1 for an initial configuration of the heat transfer model.

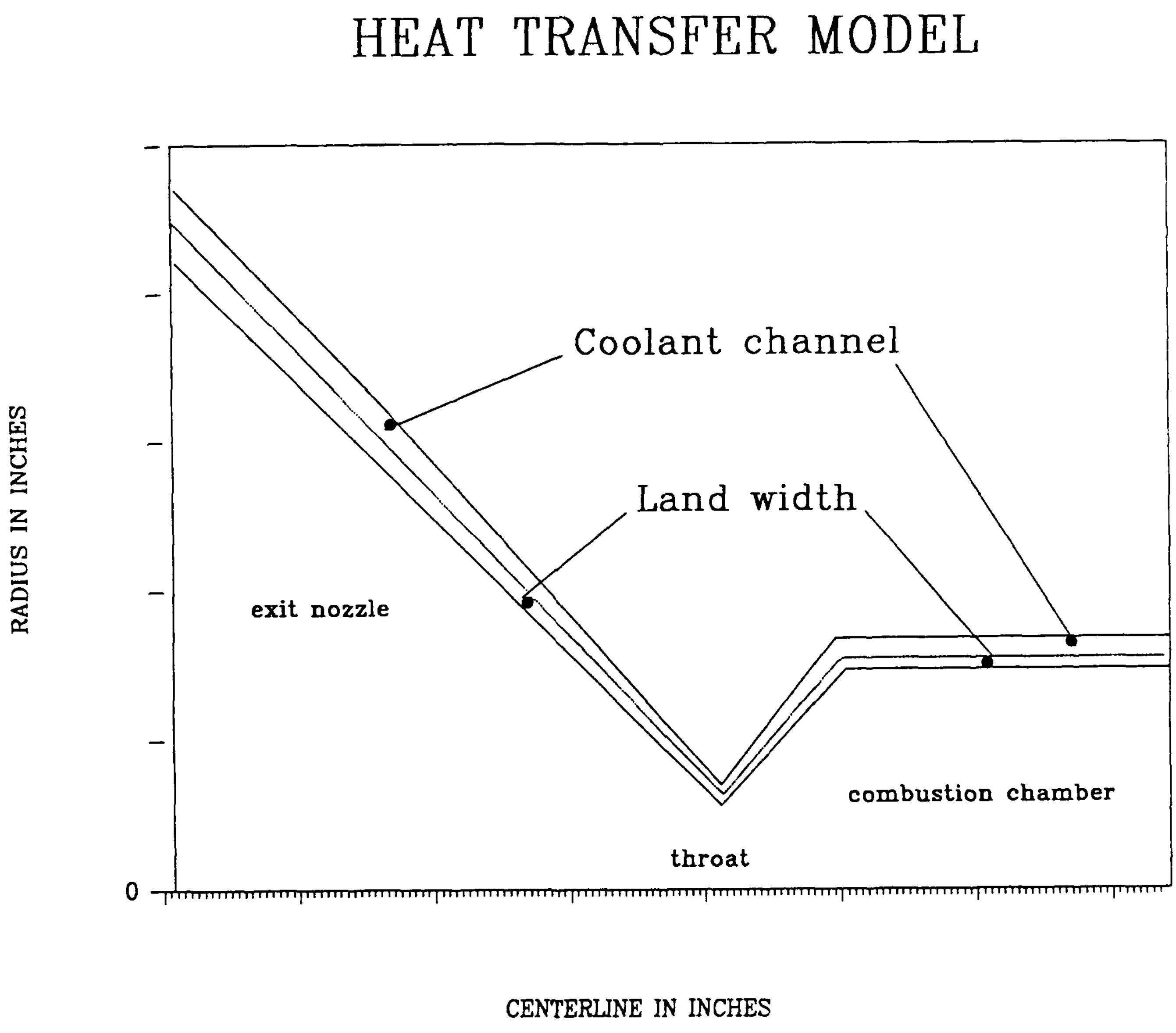

Figure 1: A side view of a heat transfer model.

c. **An Element Analysis:**

A close examination of a cross-section of a channel is necessary. Refer to figure 2 for nomenclature of the model. The heat transfer analysis will began at the exit nozzle (station 8.08) with an initial guess for the temperature of the coolant, Tc. From reference 1 page 106, the coolant-side heat transfer coefficient hc can be found.

$$hc1 = 0.029(Cp*Mu^{0.2}*G^{0.8})/(Pr^{2/3}*d^{0.2})*(Tc/T1)^{0.55} \quad (1)$$

Where

Cp = coolant specific heat at constant pressure

Mu = coolant viscositY

Pr = Prandtl number

G = coolant weight flow rate per unit area

d = coolant passage hydraulic diameter

Since the thermal conductivity of the chamber wall is made of copper and does not vary significantly with temperature, we will assume a value of 0.00125 Btu/in sec R (ref. 3). From TDK/BLM the total heat flux per unit area can be found. For the analytical treatment of conduction/convection heat transfer, Fourier's law of heat conduction was used (eqs 2-6). Thus all of the unknowns (T1, T2, Tg, hc1, hc2, Q1, Q2) can be solved at a particular station. To find the coolant temperature at the next increment, we used: delta T=Qt/(mdot*Cp), where mdot is the mass flow rate of the coolant. Upon completion, all temperatures along the coolant channel and combustion chamber will be known.

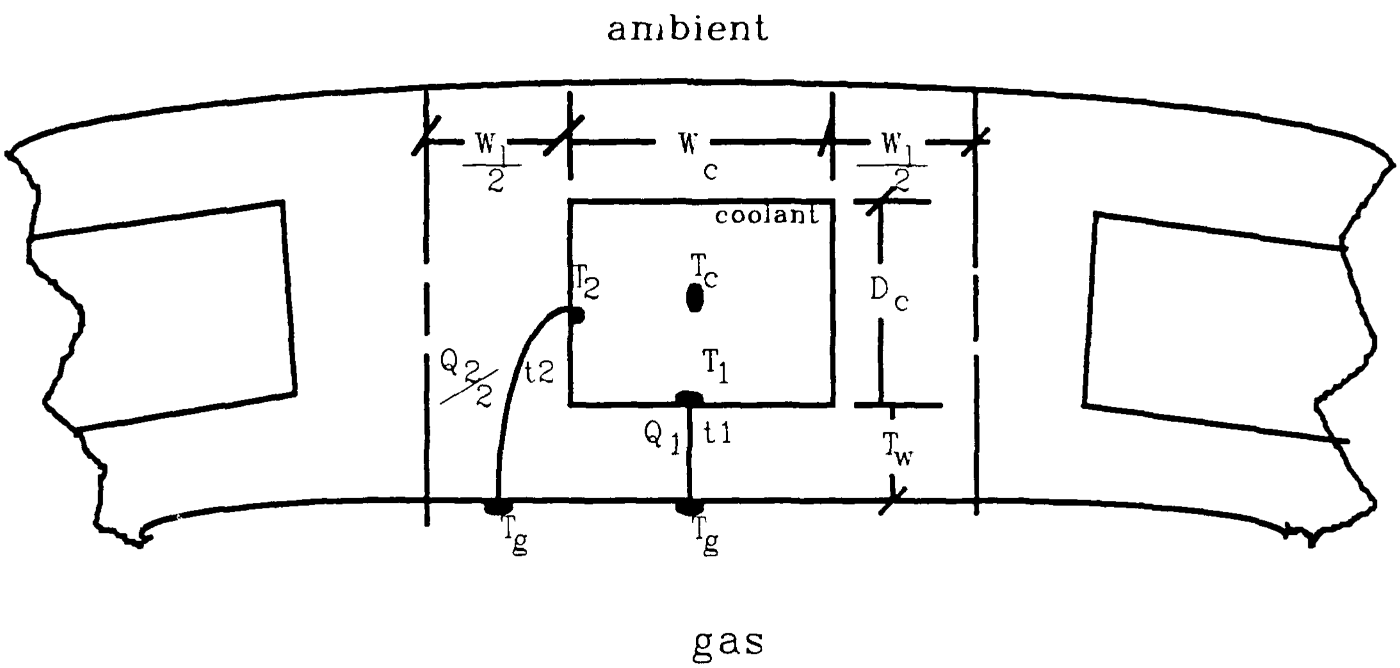

Figure 2: An element cross section of the combustion chamberr with nomenclature.

Governing Equations:

$$Q_T = Q_1 + Q_2 \tag{2}$$

$$Q_2 = h_{c2}(2D_c * x)(T_2 - T_c) \tag{3}$$

$$Q_1 = h_{c1}(W_1 * x)(T_1 - T_c) \tag{4}$$

$$Q_2 = KA_2/t_2 * (T_g - T_2) \tag{5}$$

$$Q_1 = KA_1/t_1 * (T_g - T_1) \tag{6}$$

where,

QT is the total heat transferred
hc is the heat transfer coefficient of the coolant
K is the thermal conductivity of chamber wall
x is the increment along the combustion chamber
A_1 is the area of heat flow $(W_c * x)$
A_2 is the area of heat flow $(x/2[2D_c + W_1])$

IV. CONCLUSIONS AND RECOMMENDATIONS

Once the temperatures along the coolant channel and combustion chamber are obtained for a particular geometry and chamber pressure (thrust), one can ensure that the critical properties of the walls and the propellants are not violated. From this, the acceptable operating range for N2O4 and MMH as regenerative coolants can be found as a function of chamber pressure and thrust.

I recommend that the continuation of this project be made. Since the Lotus spreadsheet could not iterate, SuperCal or Enable should be used. Also, further research should be made on the thermal conductivity of pure nickel at high temperature (600R - 1500R) for a more accurate result.

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FINAL REPORT

ROCKET NOZZLE GEOMETRY

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USAF Researcher:	Ann Krach
Date:	29 August 1988
Contract No:	F49620-88-C-0053

ROCKET NOZZLE GEOMETRY

by

Judith C. Pletsch

ABSTRACT

The SDRC Integrated Design Engineering Analysis Software (I-DEAS) solid modeling module (Geomod) was used to create an interactive program file. This program file generated a conic, parabolic, or circular arc rocket nozzle model within I-DEAS Geomod using nozzle geometry variables which were input by the user. The nozzle types and nozzle geometry variables entered were those which are used by the Two-Dimensional Kinetic Thrust Chamber Analysis Computer Program (TDK). The geometry program file was then combined with other program files which together produced a complete input deck to be run on the TDK program.

ACKNOWLEDGMENTS

I wish to thank the Air Force Systems Command and the Air Force Office of Scientific Research for sponsorship of this research. I would also like to thank Universal Energy Systems for making this program possible, and for their administrative work.

At the Astronautics Lab, I would like to thank Dick Clark for all his work and especially for all the seminars and trips he arranged. And most importantly, thanks to Ann Krach and Tom Elkins for all their patience and help, and for putting up with me and all my computer problems for the summer.

I. Introduction:

This summer I have worked in the Engineering Analysis section, under the direction of Mrs. Ann Krach. I was assigned to write a program file for the Integrated Design Engineering Analysis Software (I-DEAS) program, which would generate a rocket nozzle model from the input nozzle geometry.

I have just completed my freshman year at the University of Southern California, where I am majoring in Aerospace Engineering. This is my second summer at the Air Force Astronautics Laboratory, as I participated in the UES High School Apprenticeship Program following my senior year in high school. I have been interested in computer modeling since that time.

As a HSAP summer hire, I worked with the PATRAN program. Then, at USC I participated in the Merit Research Scholar program, in which undergraduates work directly with the engineering faculty on research projects. The professor I was assigned to was investigating the feasibility of including computer modeling in the undergraduate engineering curriculum. As a "guinea pig", I was assigned several basic problems to solve with COSMOS on the University Sun System, and then wrote an evaluation of the program for the professor.

This summer I was able to add considerably to my previous experience, working with I-DEAS. I have become skilled in

the I-DEAS Solid Modeling module, as well as with the I-DEAS command language and program files.

II. OBJECTIVES OF THE RESEARCH EFFORT:

I was assigned to work with Ann Krach and Tom Elkins in the Engineering Analysis section. Their long-range goal was to have a complete pre-processor for use with the Two-Dimensional Kinetic Thrust Chamber Analysis Computer Program (TDK). My part of this objective was to write the geometry part of this using I-DEAS program files. To do this, there were several smaller goals I had to accomplish. First, I had to learn the TDK nozzle geometry, how to use the I-DEAS Solid Modeling module (Geomod), and then how to construct the nozzle with Geomod. Secondly, and the much larger of the goals, I had to add to the basic program file to allow it to accept interactive input and construct any of the TDK nozzle shapes: spline, parabola, cone, and circular arc, and their variations.

III.

a. I spent the first week familiarizing myself with the Geomod, and learning the nozzle geometry used in TDK. (See figure 1) The model is constructed by first plotting the nozzle profile, then revolving it about the X-axis to create a three-dimensional object. The throat of a basic nozzle consists of a double circular arc contour. The throat geometry is completely specified by the throat radius, RSI; the upstream and downstream wall throat radius of curvature, RWTU and RWTD; the nozzle inlet angle, THETA I, and the nozzle attachment angle, THETA. The nozzle attaches to the throat at point A and is defined by

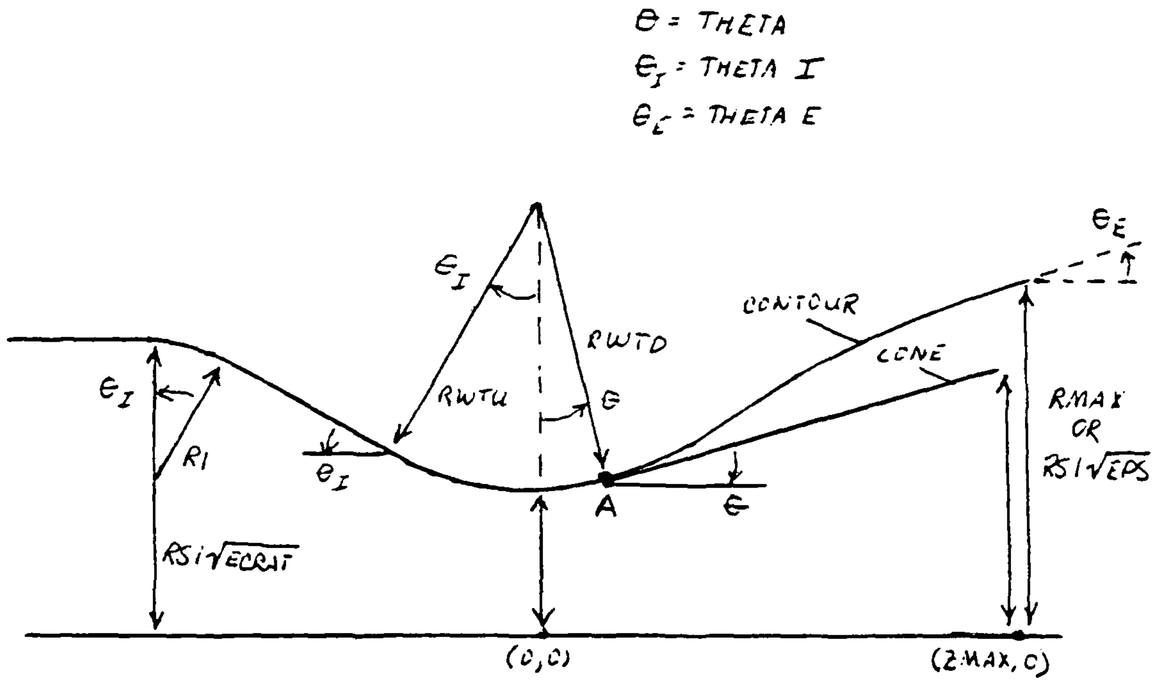

Figure 1: TDK nozzle geometry variables.

the nozzle length (measured from the throat radius), ZMAX; the exit radius, RMAX; and the expansion ratio, EPS. A parabolic or circular arc nozzle contour also includes coordinate points (Z,R), and exit radius THETA E. Finally, the inlet chamber geometry consists of the inlet contraction ratio, ECRAT, and the inlet wall radius, RI.

Next I started writing the program file. An I-DEAS program file is a text file which contains commands that operate the program as though interactive input is being entered. A program file that is created from within I-DEAS will capture all the commands entered during a session. The resulting file, when run, would re-generate the same object step-by-step.

b. This kind of program file is easy to generate, but it will only reproduce the exact nozzle that was entered. Therefore, the I-DEAS command language is added to the basic program file, allowing the user to interactively select different nozzle options and input nozzle geometry variables. The I-DEAS language will perform looping and branching operations, calculate mathematical operations, and define and use variables, so that one program file will build many types of nozzles.

IV.

a. In order to build many different types of nozzles with one program file, it is necessary to define points on the nozzle profile with equations. The throat and inlet

chamber are the same on all nozzles. The inlet radius is determined from

$$YZ = RSI \cdot \sqrt{ECRAT} \qquad (1)$$

The inlet chamber attaches to the throat at point B, found by the following two equations.

$$X_b = RWTU \cdot \sin THETA\ I \qquad (2)$$

$$Y_b = RSI + RWTU(1 - \cos THETA\ I) \qquad (3)$$

The throat inlet, point B, is connected to the throat at point (0,RSI) by a circular arc with radius RWTU. The second circular arc, of radius RWTD, joins the throat and point A. The location of point a is determined from

$$X_a = RWTD \cdot \sin THETA \qquad (4)$$

$$Y_a = RSI + RWTD(1 - \cos THETA) \qquad (5)$$

The cone nozzle outlet is the easiest to define. The nozzle attaches to point A at angle THETA, and ends at point (ZMAX,RMAX). RMAX may also be determined from the expansion ratio, EPS.

$$RMAX = RSI \cdot \sqrt{EPS} \qquad (6)$$

The parabolic contour is harder to define. It starts at point A, and ends at (ZMAX,RMAX), but in between consists

of coordinate points (Z,R) determined by the equation

$$R(Z) = a + bZ + cZ^2 \tag{7}$$

The coefficients a, b, and c are determined from the following three equations.

$$c = \frac{\dfrac{RMAX - Y_\alpha}{ZMAX - X_\alpha} - \tan THETA}{ZMAX - X_\alpha} \tag{8}$$

$$b = \tan THETA - 2cX_\alpha \tag{9}$$

$$a = Y \quad - bX_\alpha \quad - cX_\alpha^2 \tag{10}$$

b. After all of these points were plotted, they were joined by splines to form the nozzle profile. The profile was then revolved about the x-axis to form a three-dimensional object and stored in memory. The values that were generated in the program file could then be used in the TDK input deck.

V. RECOMMENDATIONS:

a. In conclusion, this summer has truly been a learning experience. When I started work I had only one semester of formal programming instruction or experience, and although it does what it is supposed to do, the style of my program file reflects that. But I feel that I have learned a lot writing it, and if I ever had a chance to re-write the program, it would be much better. I also feel that I now have a jump on most of the others in my class at USC, and that the experience I have gained will help me in my studies there.

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FINAL REPORT

COMPUTER AIDED COMPOSITE DESIGN AND EMBEDDED SENSORS

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Department:	Aeronautical Engineering
USAF Researcher:	James L. Koury

Date:	1 Aug 88
Contract No:	F49620-88-0053

COMPUTER AIDED COMPOSITE DESIGN AND EMBEDDED SENSORS

by

Gregory J. Price

Abstract

Two computer programs for composite analysis were developed and the different parameters that effect embedded sensors were investigated. The first program analized a pressure vessel using netting analysis. The second program predicted the frequency of a plate or a cylinder. The program predicted a frequency of 42.8 Hz for a plate compared to 45.1 Hz measured and 9.7 Hz for a cylinder compared to 10.4 Hz measured. A laminate plate theory program was used in conjunction with the frequency prediction program, writen by Steven Tsai.

An epoxy beam and several laminated beams were used as test samples for the embedded sensors. Investigation has found that the main areas of concern are insulating the wire to sensor connections and getting the lead wire out of the test sample. Teflon tape and RTV based coatings were found to work the best for insulating the connections. Removable roll pins and hypodermic needles was found to be the most efficent way of getting the lead wires out of the sample.

ACKNOWLEDGEMENTS

I wish to thank the Air Force Systems Command and the Air Jorce Office of Scientific Research for sponsorship in this research. I also wish to thank Dr. Clarence Calder whom I worked under for the embedded sensor protion of my research and Sgt. Dave Lemely for assisting me with several technical problems. I especially wish to thank James Koury for all his help.

I. INTRODUCTION

Analysis of composite structures requires a significant number of mathamatical operations, for which computers are ideally suited. However, the physical principals of composites must be understood prior to useing these programs.

Embedded sensors have the ability to monitor the health or a composite, control and monitor the vibrations, and can measure the strain. Embedding sensors also has the advantage of protecting the sensor and monitoring the composite while it is being cured.

The Components Laboratory has been designated to investigate the use of composites in space structures this matches my primary interest, the design of space structures. My work with a zero-gravity TIG welding experiment lead to my assignment at the Components Laboratory.

II. OBJECTIVE

The primary objective of this research effort was to write programs to be used in composite design and analysis. A secondary objective was to assist with the construction of embedded sensor test samples.

Laminate plate theory is the primary method for analyzing composites. To use laminate plate theory the composite matrix must first be entered into a computer data base. Programs are available for this but laminate plate theory must be understood prior to their use. A simplification of laminate plate theory is the netting equation. However, if there is an extensive amount of data a computer program would reduce the number of errors. The same would be true for finding the frequency of a plate or cylinder.

Embedding sensors in a composite material gives the ability to monitor the health, reduce vibration, and measure the strain of the composite. In order to embed sensors in a composite two unkrıown parameters must be resolved, insulaton of the sensors and protection of the lead wires.

III. COMPUTER AIDED COMPOSITE ANALISIS

Two computer programs were writen, but to utilize them two additional programs written by Steven Tsia are required. The two writen programs are for analysis of a pressure vessel and for predicting the frequency of a beam. An explanation of the netting equation, used in the pressure vessel analysis, has been included. Explanations of programs for the matrix properties, laminate plate theory, and frequency prediction have been writen and are avilable on request.

```
100 PRINT "THIS PROGRAM COMPUTES THE PERFORMANCE FACTORS FOR"
110 PRINT "A FILAMENT WOUND BOTTLE"
120 PRINT "*******";PRINT
121 INPUT "DO YOU KNOW THE AREA ENDS (Y/N)";A$
122 IF     A$="N" GOTO 130
123 INPUT "WHAT IS THE HOOP AREA END (in) ",AX
124 INPUT "WHAT IS THE HELICAL AREA END (in) ";AY:PRINT
125 GOTO  200
126 REM
130 PRINT "THIS SECTION OF THE PROGRAM CALCULATES THE HOOP AREA END"
140 REM
150 INPUT "WHAT IS THE HOOP WEIGHT PER METER (gm/m)",WY
160 INPUT "WHAT IS THE HOOP DENSITY (gm/cm3)";DY
170 AY=(WY/DY)/100/6.45
180 PRINT:PRINT "THE HOOP AREA END IS"AY"in2"
181 PRINT "*******";PRINT
190 REM
191 PRINT "THIS SECTION OF THE PROGRAM CALCULATES THE HELICAL AREA END"
192 REM
193 INPUT "WHAT IS THE HELICAL WEIGHT PER METER (gm/m)";WX
194 INPUT "WHAT IS THE HELICAL DENSITY (gm/cm3)";DX
195 AX=(WX/DX)/100/6.45
196 PRINT:PRINT "THE HELICAL AREA END IS "AX"in2"
197 PRINT "*******":PRINT
198 REM
200 PRINT "THIS SECTION OF THE PROGRAM CALCULATES THE HOOP THICKNESS"
210 REM
220 INPUT "WHAT IS THE HOOP BAND WIDTH (in)";BW
230 INPUT "WHAT IS THE NUMBER OF PLYS IN THE HOOP";PY
240 HPTH=(AY*PY)/BW
250 PRINT:PRINT "THE HOOP THICKNESS IS";HPTH
251 PRINT "*******":PRINT
260 REM
270 REM*** THIS SECTION OF THE PROGRAM CALCULATES THE HELICAL THICKNESS ***
280 REM
290 INPUT "WHAT IS THE LONG ANGLE (deg)";LA
300 INPUT "WHAT IS THE ARM ANGLE (deg)";AA
310 INPUT "WHAT IS THE BOTTLE DIAMETER (in)";BD
315 INPUT "WHAT IS THE NUMBER OF HELECAL PLYS";PX
320 H1LBW=(LA/360)*(3.14*BD)*(COS(AA/57.3))^2
330 H2LTH=(AX*PX)/BW
340 PRINT:PRINT "THE HELICAL BAND WIDTH IS "H1LBW"in"
350 PRINT "THE HELICAL THICKNESS IS "H2LTH"in"
351 PRINT "*******":PRINT
360 REM
370 REM*** THIS SECTION OF THE PROGRAM CALCULATES THE STRESS RATIO ***
380 REM
390 SR=.5*(PX/PY)*(AX/AY)/((COS(AA/57.3))^2*(1-.5*(TAN(AA/57.3))^2))
400 PRINT "THE STRESS RATIO, HELICAL/HOOP, IS "SR
401 PRINT "*******":PRINT
410 REM
420 REM*** THIS SECTION OF THE PROGRAM CALCULATES THE HOOP STRESS ***
430 REM
440 INPUT "WHAT IS THE BOTTLE PRESSURE (psi)";PS
450 SH=((PS*(BD/2))/HPTH)*(1-.5*(TAN(AA/57.3))^2)
460 PRINT:PRINT "THE HOOP STRESS IS "SH"ksi"
470 PRINT "*******"
480 INPUT "DO YOU WISH TO CONTINUE (Y/N)";C$
490 IF     C$="N" GOTO 530
500 INPUT "ARE THE AREA ENDS THE SAME (Y/N)";E$
510 IF     E$="Y" GOTO 200:PRINT "*******":PRINT
520 GOTO 130
530 PRINT:PRINT  "BYE-BYE"
540 END
```

```
100 PRINT "THIS PROGRAM FINDS THE REQUIRED STIFFNESS BY MODAL ANALYSIS"
110 PRINT "AND THE EFFECTIVE STIFFNESS BY L.P.T. FOR COMPARISON."
115 INPUT "IS THE BEAM A CYLINDER OR A PLATE (C/P)"; BM$
120 REM
129 REM
130 REM *** THIS SECTION IS THE REQ. STIFFNESS PORTION OF THE PROGRAM ***
131 REM
140 REM
150 PRINT:PRINT "**********"
160 INPUT "DO YOU WANT TO FIND THE REQUIRED STIFFNESS (Y/N)";DR$
170 IF DR$="N" GOTO 300
180 REM
190 REM *** THIS SECTION INPUTS THE VALUES FOR REQ. STIFFNESS ***
200 REM
210 INPUT "WHAT IS THE FREQUENCY (Hz)";FQ
220 INPUT "WHAT IS THE MODE NUMBER";MN
230 INPUT "WHAT IS THE DENSITY (lbm/in3)";DN
240 IF BM$="C" THEN INPUT "WHAT IS THE MEAN RADIUS (in)";R
245 IF BM$="P" THEN INPUT "WHAT IS THE WIDTH (in)";W
250 INPUT "WHAT IS THE WALL THICKNESS (in)";TH
260 INPUT "WHAT IS THE BEAM LENGTH (in)";L
270 REM
280 REM *** THIS ARRAY IS THE MODES OF A CANTILEVER BEAM ***
290 REM
300 MS(1)=1.8751
310 MS(2)=4.69409
320 MS(3)=7.85475
330 MS(4)=10.99554
340 MS(5)=14.13716
350 MS(6)=17.27875
360 MS(7)=20.42036
370 MS(8)=23.56194
380 MS(9)=26.70353
390 MS(10)=29.84514
392 IF AR$="Y" GOTO 430
395 IF DR$="N" GOTO 530
400 REM
410 REM *** THIS SECTION CALCULATES THE REQ. STIFFNESS
420 REM
430 PRINT "**********"
440 IF BM$="C" THEN RS=(DN*TH^3*L^4*(FQ*6.28319)^2)/(MS(MN)^4*R^2*2316.528)
450 IF BM$="P" THEN RS=(DN*TH*L^4*(FQ*6.28319)^2)/(MS(MN)^4*386.088)
460 PRINT "THE REQUIRED STIFFNESS IS "RS" lbin"
470 PRINT "**********":PRINT
480 REM
490 REM
500 REM *** THIS IS THE L.P.T. PORTION OF THE PROGRAM ***
510 REM
520 REM
530 PRINT:PRINT
540 INPUT "DO YOU WANT TO FIND THE EFFECTIVE STIFFNESS (Y/N)";DS$
550 IF DS$="N" GOTO 970
560 REM
570 REM *** THIS SECTION INPUTS THE VALUES FOR EFFECTIVE STIFFNESS ***
580 REM
590 INPUT "WHAT IS D11 (lbin)";D1
595 IF BM$="P" GOTO 700
600 INPUT "WHAT IS D12 (lbin)";D2
610 INPUT "WHAT IS D16 (lbin)";D3
620 INPUT "WHAT IS D22 (lbin)";D4
630 INPUT "WHAT IS D26 (lbin)";D5
640 INPUT "WHAT IS D66 (lbin)";D6
650 REM
660 REM *** THIS SECTION CALCULATES THE EFFECTIVE STIFFNESS ***
```

```
680 DE=D4*D6
690 ES=D1-(D2*(D2*D6-D3*D5)/DE)+(D3*(D2*D5-D3*D4)/DE)
700 REM
710 REM *** THIS SECTION CALCULATES THE ASSOCIATED FREQUENCY ***
720 REM
730 INPUT "DO YOU WANT TO FIND THE ASSOCIATED FREQUENCY (Y/N)";DAF$
740 IF DAF$="N" GOTO 950
750 REM
760 REM *** THIS SECTION INPUTS THE VALUES FOR THE ASSOCIATED FREQUENCY ***
770 REM
780 IF (DR$="N")OR(AR$="Y") GOTO 820
790 INPUT "DO YOU WANT TO USE THE INPUT VALUES USED IN MODAL ANALYSIS";DM$
800 IF DM$="N" GOTO 820
810 GOTO 870
820 INPUT "WHAT IS THE MODE NUMBER";MN
830 INPUT "WHAT IS THE DENSITY (lbm/in3)";DN
840 IF BM$="C" THEN INPUT "WHAT IS THE MEAN RADIUS (in)";R
845 IF BM$="P" THEN INPUT "WHAT IS THE WIDTH (in)";W
850 INPUT "WHAT IS THE WALL THICKNESS (in)";TH
860 INPUT "WHAT IS THE BEAM LENGTH (in)";L
870 REM
890 REM *** THIS SECTION COMPUTES THE ASSOCIATED FREQUENCY ***
900 REM
910 PRINT "**********"
920 IF BM$="C" THEN AF=(SQR((ES*MS(MN)^4*R^2*2316.528)/(DN*TH^3*L^4)))/6.28319
925 IF BM$="P" THEN AF=(SQR((D1*MS(MN)^4*386.088)/(DN*TH*L^4)))/6.28319
930 PRINT "THE ASSOCIATED FREQUNCY IS "AF" Hz"
940 PRINT "**********"
945 IF BM$="P" THEN GOTO 970
950 PRINT "THE EFFECTIVE STIFFNESS IS "ES" lbin"
960 PRINT "**********":PRINT
970 INPUT "DO YOU WANT TO COMPUTE ANOTHER REQUIRED STIFFNESS (Y/N)";AR$
980 IF AR$="Y" GOTO 210
990 INPUT "DO YOU WANT TO COMPUTE ANOTHER EFFECTIVE STIFFNESS (Y/N)";AE$
1000 IF AE$="Y" GOTO 560
1010 END
```

IV. THE NETTING EQUATION

The netting equation is used to find five factors that are needed to analize the performance of a pressurized filament wound bottle. A typical bottle is shown in figure 1.

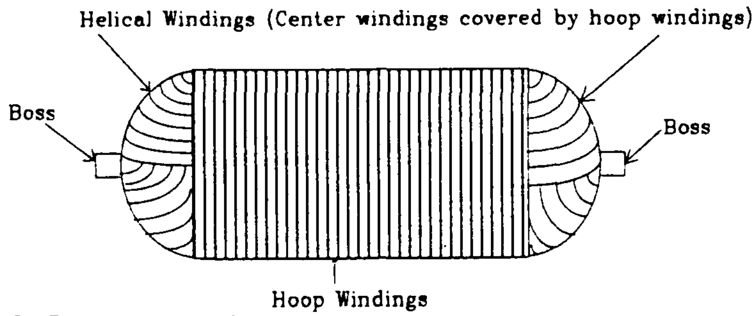

Figure 1. Pressure vessel.

The first performaned factor calculated by the netting equation is the area end. Physically the area end is the cross sectional area of the fiber, the area end is shown in figure 2.

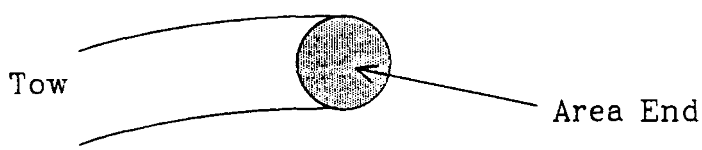

Figure 2. Area end.

It is necessary to find the area end for later calculations. The area end is found by:

$$\text{Area end}=[\text{Weight}]\left[\frac{1}{\text{Density}}\right][\text{Convertion Factor}] \qquad (1)$$

The weight, also called the yield, is measured in gm/m. The density of the fiber is measured in cm^3/gm. With the conversion factors of 100 m/cm and $1in^2/6.45cm^2$ the area end will be in units of in^2.

The second parameter that is calculated is the hoop thickness. This value must be found to accomplish later calculations. It is found by:

$$\text{Hoop Thickness}=\left[\frac{\text{Area End}}{\text{Hoop Band Width}}\right][\text{Number of Hoop Plys}] \qquad (2)$$

The hoop band width is the width of the fiber, or the distance the fiber is advanced along the cylindrical portion of the bottle, it is measured in inches. The number of hoop plys is how many layers of fibers there are wraped around the bottle.

The third parameter, the helical thickness, is calculated in the same manner as the hoop thickness. It is found by:

$$\text{Helical Thickness} = \left[\frac{\text{Area End}}{\text{Helical Band Width}}\right][\text{Number of Helical Plys}] \qquad (3)$$

However, the helical band width is calculated by:

$$\text{Helical Band Width} = \left[\frac{\text{Long Angle}}{360^{\circ}}\right][\pi][\text{Bottle Diameter}][\text{Cos}^2(\text{Arm Angle})] \qquad (4)$$

The longal angle, measured in degrees, is the angle that the fibers advance longitudinally as the bottle is wound. The longal angle is shown figure 3.

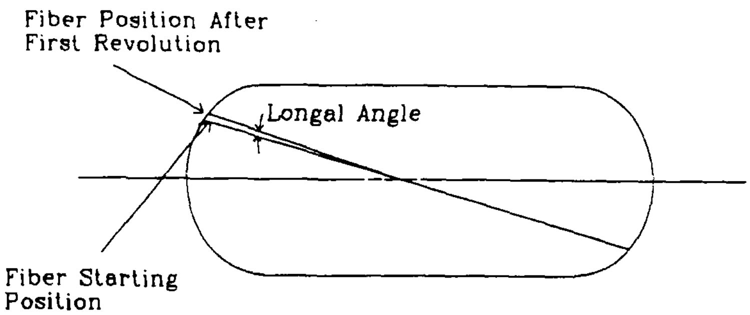

Figure 3. Longal angle

The arm angle, measured in degrees, is an off set to prevent the bosses from being wound inside the bottle along with the mandral. The arm angle is shown in figure 4.

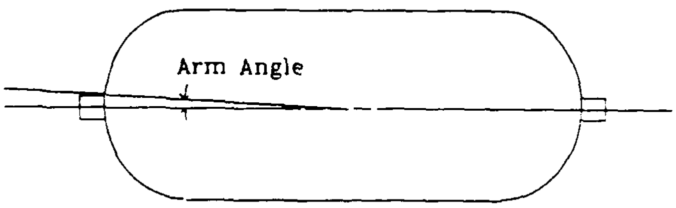

Figure 4. Arm angle.

The fourth calculated performance factor is the ratio of the helical stress to the hoop stress. This value is useful in analizing where the forces will be concintrated. A proper value is about .5. If the ratio is high the forces will be transfred to the ends this is

undesirable since the ends are the weakest points. If the ratio is too low then the bottle will be unnecessarily heavy. The ratio is found by:

$$\frac{\text{Helical Stress}}{\text{Hoop Stress}} = \frac{\frac{1}{2}\left[\frac{\text{Number of Helical Plys}}{\text{Number of Hoop Plys}}\right]\left[\frac{\text{Helical Area End}}{\text{Hoop Area End}}\right]}{\left\{\text{Cos}^2(\text{Arm Angle})\left[1-\frac{\text{Tan}^2(\text{Arm Angle})}{2}\right]\right\}} \qquad (5)$$

The fifth calculated value is the hoop stress. This is calculated because the hoop fibers carry most of the load, this is known from our calculations of the helical to hoop stress ratio. The hoop stress may also be used to estimate the burst pressure. The hoop stress is found by:

$$\text{Hoop Stress} = \frac{[\text{Pressure}][\text{Bottle Radius}]}{[\text{Hoop Thickness}]}\left[1-\frac{\text{Tan}^2(\text{Arm Angle})}{2}\right] \qquad (6)$$

The pressure is measured in psi. The radius and the hoop thickness are measured in inches. The hoop stress will be in units of psi.

To aviod tedious and repetative calculations a program has been writen to calculate these values. This program may be acessed by typing in the following commands. To begain bring up the disk drive on the computer. *Type in: basic <CR>.* At this time the Full Screen Editor will appear. Next push the F3 botton and type in: neteqtn2. This will display LOAD"neteqtn2. Now push the <CR>, this loads the netting equation program into the computer. If you wish to inspect the program push F1 and type in 100-251<CR>, this displays lines 100 to 251. To display the remainder push F1 again and type in 251-530. To run the program push F2 and follow the program instructions.

IV. EMBEDDED SENSORS

Two types of test samples were made, an epoxy beam made from 55A resin and a twelve ply unidirectional laminated plate made from graphite/epoxy prepreg.

Prior to manufacturing the test samples the different soldering techniques for attaching the sensors to exit wire was investigated. The next subject studied was application technics for electrical isolation of exit wires. The insulators studyed were teflon tape, silicon paint, epoxy, and spray paint.

The second subject investigated was to embed a strain wire, a strain gage, and two piezo electric sensors in the epoxy beam. After manufacturing the beam, it was placed under various loads and each sensor's output was checked.

Two AS4/epoxy laminates were layed-up. The first was layed up with graphite tows, strain wire, strain gages, and piezo electric crystals with each type of insulation on the different sensors. Problems with lead wires, especially the graphite tows, sticking to the plate during the cure cycle were encountered. Repair of some test specimans was required. These problems have been resolved with the second laminate by using hypodermic needles mounted on cured graphite/epoxy bases and roll pins mounted in the mandral.

VIII. RECOMMENDATIONS

The computer programs may be used in the following manner. Programs MATFIX and GENLAM may be used for design or analysis problems. The netting equation may be used to pr. ict the burst pressure of a bottle. The beam frequency program may be used to design a beam so that avliable equipment can measure the first ten modes of the test speciman.

I recommend that the data base of program MATFIX be built up with manufacturer provided data and verified by the Components Laboratory.

References

1. Tsia, Steven, Composite Design, Dayton, Ohio,Think Composites.

1988 USAF-COLLEGE SCIENCE AND ENGINEERING PROGRAM

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FINAL REPORT

Fabrication and Processing of Carbon-Carbon Structures

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Date: 6 September 1988

Contract No.: F49620-88-C-0053

Fabrication and Processing of Carbon-Carbon Structures

by

Janet M. Reust

ABSTRACT

Several different Carbon-Carbon structures were fabricated out of prepreg using a variety of lay-up patterns. The main structures created were two inch diameter cylinders consisting of four layers of prepreg. Some examples of lay-up patterns included the material's warp set at zero degrees, ninety degrees, an alternation of the two, and a forty-five degree spiral wrap. These differing cylinders will undergo strength tests when the process of turning them into Carbon-Carbon structures has been completed. Also various lay-up patterns were devised to create an unwarped, twelve inch diameter mirror. In addition to this, the entire process starting with the prepreg lay-up and ending with a Carbon-Carbon structure, was studied.

I. INTRODUCTION:

In June of 1989 I will graduate from the University of Ca. at Santa Barbara with a B.S. degree in Chemistry, which I intend to apply to the field of material science. This is the second summer that I've worked at the AF. Astronautics Laboratory, where my exposure to the Components Laboratory the previous summer led me to become interested in composite materials. Because of this I requested to be reassigned there for the summer of 1988. My experience working with composite materials greatly helped my research this summer in the area of Carbon-Carbon structures. My first summer at the Components Laboratory offered me the opporutinity to become familiar with the fabrication and winding of graphite-epoxy structures. Also I recieved experience in laying up prepreg in the fabrication of Carbon-Carbon structures, where my interest still remains.

One of the main reasons that the Components Laboratory was created was to further the research and development of composite space structures. As composites are on a whole much stronger and lighter than steel their use in space is very desirable, as it would result in lighter payloads and less expense. A variety of facilities and equipment are thus available at this lab for research purposes. These include both computer and mechanical winders for graphite-epoxy fabrication, a prepreg lay-up room for fabrication of

Carbon-Carbon structures, testing facilities, and a microscopy area. My work was done mainly in the prepreg lay-up room. There, I was responsible for cutting the prepreg, devising differing lay-up patterns in an attempt to increase strength, and laying up the structures. These were then placed in an autoclave to cure, after which they awaited the next step in the process of becomming Carbon-Carbon structures.

The accuracy and precision used in the lay-up process plays a large part in determining the quality of the final structure. A good example of this can be seen in the research done to create a round, concave mirror with no warping. Depending on the design, we obtained structures that were severely warped, only very slightly warped, and many in the range in between. This was mainly the type of research I did this summer, for which my experience and knowledge from the previous summer was a great asset.

II. OBJECTIVES OF THE RESEARCH EFFORT:

At the beginning of my eleven week appointment at the AFAL. Components Laboratory, I had three main objectives. The first, and most interesting to me was to attempt to design and build a concave mirror using a standard Carbon-Carbon lay-up and heat treatment method. This is a relatively new idea and so far has not been successfully carried out anywhere. This offered a challenging research

opportunity. One of the main problems we faced was to end up with a finished product that was not warped, and which kept the shape of the mandrel used to lay it up. This involved much experimentation in devising symmetric lay-up patterns.

The second project I was involved with dealt with the construction of cylindrical structural components. Prior to my arrival at the Components Laboratory a cylindrical structure of diameter .5 in. and length 10 ft. had been made, but had become deformed on heat treating. Also trouble had been encountered when attempting to remove the structure from the mandrel it had been cured on. My goal was to create a linearly straight structure, which could be removed from its mandrel after curing.

The third and final project I had planned to work on consisted of learning how to run and operate a large chemical vapor deposit (CVD) furnace. Unfortunately I did not get to do this, as during its single run of the summer I was busy on another project. I did instead, though, learn how to run and operate an autoclave. I used this machine extensively during my eleven weeks and became very familiar with its operations.

An additional project begun consisted, again, of devising a lay-up pattern to this time create cylinders with a 2 in. diameter. Many different patterns were tried, including two different lay-up methods. These cylinders

were created to be tested for strength, and to simulate the shape of possible space structures. These were unable to be tested this summer as the process to make Carbon-Carbon is a long one. Eventually when this process is completed, though, the cylinders will go through tests to determine which lay-up pattern results in the strongest material

III.

The first project I began work on was the construction of a 10 ft. long cylindrical structure with a .375 in. diameter. This was fabricated from prepreg, a material consisting of a woven cloth of carbon fibers coated in a phenolic resin. In prepreg there are two sets of fibers that run perpendicular to eachother. These are called the warp, which runs the length of the material, and the fill which runs the width of the material.

To begin, exact measurements were made of the mandrel's diameter so that the circumference could be calculated and thus the width of each prepreg layer determined. For this lay-up pattern four layers were used consisting of two that were 10 ft. long, one 6 ft. long, and one 3 ft. long. The shape of the layers were simply long, slender strips which were heat formed around the mandrel, one at a time, so that straight seams were formed down the length of the mandrel. These were applied so that the warp of the material ran parallel with the mandrel, and the seams were 90° apart from

each other.

As each successive layer was applied to the mandrel it went through a debulking process. This consisted of wrapping shrink tape around the layers and placing the mandrel in an autoclave for 15 min. at 210 F. After this had been done to all four layers the structure was ready to be cured. For this a vacuum bag was placed around the mandrel which had been wrapped with release and bleeder cloths, and it was put in an autoclave to undergo a 4 hr. cure cycle. During this cycle the temperature is brought up to 210°F where the resin has the consistency of water, then 200 psi is applied, along with the original vacuum , in order to let the resin flow properly and keep the cylindrical shape. This mainly occurs when the temperature is brought up to 325°F and 400 psi is applied, where it remains for 3 hrs. Once the cure cycle has been completed, the structure may be removed from its mandrel to begin the next step of the Carbon-Carbon process.

Two major problems arose during the course of this project, one being the failure to successfully remove the structure in one piece from the mandrel after curing had been completed. During the cure cycle a large amount of resin flows which can act almost like a glue adhering the structure to the mandrel, unless a release coat is applied. The difficulty arose from the fact that the mandrel is very long and has a very small diameter. We attempted to resolve

this problem by cleaning the surface of the mandrel thouroughly with acetone and steel wool, putting on two layers of clear boot polish (wax), and polishing the mandrel. After this three layers of a teflon release agent (Frekote 44) were sprayed on and when this had dried more layers of wax were added. The theory behind this was that three planes of release would be formed: one between the prepreg and the wax, a second between the wax and release agent, and a third between the wax and metal of the mandrel.

On the first attempt the structure we were trying to twist free from the mandrel broke at the 3 ft. mark. On our second try we decided to change the lay-up pattern. This one consisted of five layers each of length 10ft., 8 ft., 6ft., 4ft., and 2ft., respectively. The method of applying the release coat and wax was not altered. After all of the layers had been debulked the structure was successfully removed from the mandrel, which was cleaned and recoated with wax and release agent, and put back in to undergo the cure cycle. After this had been completed a cautious attempt was made to remove the structure, but it was decided to allow the structure to remain on its mandrel and to proceed to the next step in this manner.

The next step after curing is called baking and the structure is placed in an oven where the temperature is brought up to 1600°F. This is a rather tedious process as the temperature can only be raised 3 degrees per hour in

order to prevent the material from cracking as gasses escape from it. Currently, this structure and mandrel are being stored in a freezer awaiting this next step, and the installation of a large furnace which will allow it to proceed.

The second major problem encountered was in determining the width of prepreg to be cut. The equation used was that for the circumference of a circle, and for the first layer the diameter used was that measured from the mandrel. For the second layer, twice the thickness of the prepreg had to be added to the diameter measurement to calculate the new and slightly larger circumference. The actual thickness of the prepreg is approximately .01 in., but this number changes during the cure cycle when the resin flows. Eventually when the material comes to the point in the Carbon-Carbon process when all the resin has been burned off, the thickness is approximately .0005 in. Theoretically, if the circumferences were calculated using the .0005 in. thickness then once all of the resin had burned off all of the fibers in each seam would meet up exactly. In practice though this did not happen and a rather large gap remained after the cure cycle. If actual measured circumferences were used which allowed the seams to meet exactly during the lay-up process, with no gap present, wrinkles were found in the structure after the cure cycle most likely caused by the over abundance of material present. Different approaches

were taken to this problem, one being to average the calculated circumference with the measured circumference, but this was not found to be very satisfactory either. One of the main factors influencing this problem was that during the cure cycle the structure adopts its final shape, but not all of the resin has been burned off, so gaps present at this stage remain.

The second phase of this project consisted of laying up cylinders with an average diameter of 2 in. and length 1.5 ft. The mandrels used for this were constructed out of steel and had slight tapers to them of approx. .17 in. A variety of lay-up patterns using four layers each were tried out on these mandrels in order to test the strength of the pattern. The main differentiating factor between the lay-ups is the direction in which the warp runs. Lay-up patterns were created with the warp running parallel (0) to the mandrel for all four layers, perpendicular (90) for all four layers, and an alternation of the two. These were all done with a flat wrap of the prepreg resulting in a straight seam. These same patterns were also done with a 45° spiral wrap, whose measurements were calculated using trigonometric equations. Further variations included a 45° spiral wrap where the warp was at a 45° angle to the mandrel and in a 0°, +45°, -45°, 0° pattern. The direction in which the warp runs will have an effect on the strength of the finished material. These cylinders still have to go through many

processes before they become Carbon-Carbon , and before they can have their strength tested.

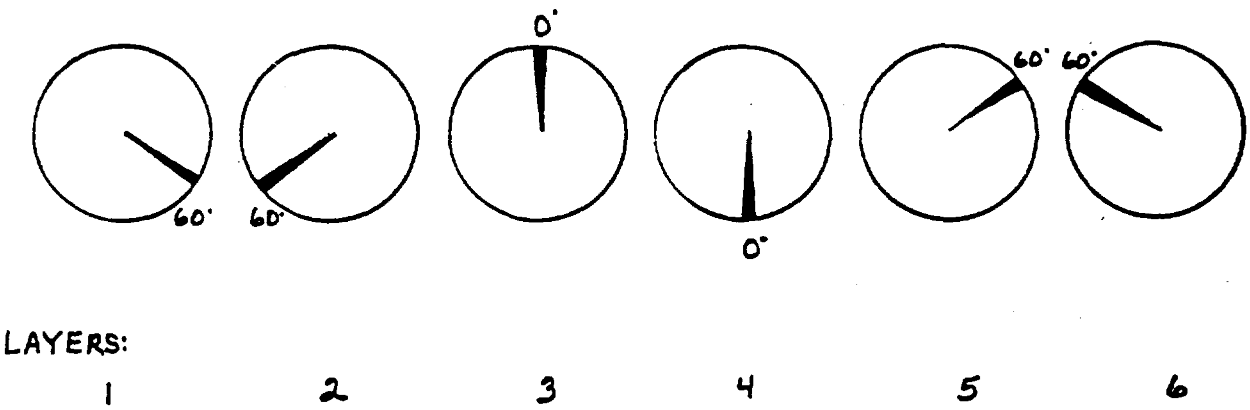
The second project I worked on involved the fabrication of a Carbon-Carbon mirror. The mandrels which we used were constructed out of graphite and were mated, one having a convex surface and the other a concave surface. These were waxed with clear boot polish and two coats of release agent were applied. A problem arose in devising a lay-up plan that would result in a smooth surface and an unwarped structure. The first attempt consisted of cutting out 12 in. diameter circles of prepreg, making a slit along the warp from the center out, and heat forming them on the concave mandrel. The overlapping part of the prepreg at the slit created by the curvature of the mandrel was cut out of it. It was calculated that a .28 in. wedge should be cut out of the 12 in. circle so the ply would be able to fit smoothly in the mandrel with the ends of the seam closely butted up against eachother. It was observed however that a slight, football shaped gap was present caused by much material being present at the outer edge of the circle. To counteract this a small slice of material was cut off each side of the wedge starting 3 in. into the circle and moving out to the edge of the circle. The first mirror was six plys thick and was constructed in such a manner that the seams were 60° from eachother. The mirror was not debulked and was cured by the usual cycle with both mandrels in place and teflon release and bleeder cloths between the mandrel

surfaces and prepreg. The result was a mirror that was slightly warped with a surface reflecting the imprint of the teflon release cloth.

In order to do away with the imprint it was decided to not use the release and bleeder cloths again. Also in an attempt to get rid of the warping a lay-up plan in which the seams and thus the warp were symmetric about the center was adopted. In the meantime various other lay-up plans were experimented with. One of these consisted of cutting 12 wedges out of a prepreg circle. This was abandoned for reasons of practicality. Also cutting a circle into quarters and shaving a small amount of of each wedge was experimented with, but was dropped as a suitably symmetric pattern could not be achieved without overlapping the seams on two successive layers. Thickness was also speculated about as contributing to the amount of warping present and so a twelve layer mirror was constructed. This followed a centrally symmetric lay-up plan with a wedge cut from each circle. This method produced our best product, with only a slightly noticeable warp and smooth surfaces, as no seams were visible and no curing cloths were used.

Another possible factor contributing to the warping of the mirrors was that both concave and convex halves were used in the curing process with the mirror sandwiched between them. These halves do not meet up exactly due to a slightly raised area in the center of each of them, created

when they were machined. In a mirror of only six layers this discrepancy would tend to show up as a warp as the mirror is so thin. In a twelve layer mirror though because of the added thickness, the effect would not be so noticeable. We decided to lay-up a mirror using only one half of the mandrel, and have received good results from this. Also, warping seems to lessen a great deal after the carbonization step. From our research it was concluded that the best lay-up plan is as follows:



WARP FOLLOWS DIRECTION OF WEDGE

Because I was constantly using the autoclave in debulking and curing processes, I gained a thorough knowledge of its operation and procedures. This included using both a Micristar programmer and setpoints to operate the temperature, pressure, and vacuum options of the autoclave. I feel that learning how to operate this machine helped to round out my experience here at the Components Laboratory.

There are many different aspects of research processes including the reading of background material on the subject matter, devising and planning an experiment, and actually using the equipment to carry it out and collect the data. Interpretation and future application of the results are also a major part of advancing research. This also includes being able to maturely deal with the setbacks and frustration associated with failure and to get back on track and learn from them when they occur. My experience this summer at the Components Laboratory has exposed me to all of this and taught me some very valuable lessons about research which I will carry with me as I continue to further my education and my career.

IV. RECOMMENDATIONS:

Because the process of manufacturing Carbon-Carbon is so lengthy, I was not able to o)tain the end results of the research I was involved with this summer. I have completed

the initial steps of making Carbon-Carbon structures up to and including the carbonization process. This is the step which is taken after the structures have been cured, and in this they are placed in an oven and the temperature is raised to 1600° F. This is a long process as the temperature can only by raised 3° F per hour in order to prevent the material from developing cracks as gasses are given off. After this step the structures must be graphitized in another furnace by bringing the temperature up to 4600° F at a rate of 100° F per hour. It is during this step that the structure of the material changes from non-crystalline to crystalline. The next step is to pitch impregnate the material, in which hot coal tar pitch is forced into the tiny pores of the material. This step helps to increase the density. Once this has been completed the structure must undergo the carbonizing, graphitizing, and pitch impregnating steps two more times ending with the graphitization step. The result of this is a composite material called Carbon-Carbon.

Once this has been done to the structures I have fabricated this summer, testing for strength can begin on the cylinders to determine which lay-up pattern provides the strongest material. Further research should also be carried out to determine the correct circumference to use when laying these up so that there is no gap which could weaken ıe structure, and also no wrinkles. Testing will be carried

out on the mirrors to determine if any warping or distortion of the surface is present. The results of this will provide a clearer direction toward which further research should be directed.

Acknowledgements

I would like to thank the Air Force Office of Scientific Research as well as the Air Force Systems Command for sponsoring this research, and Universal Energy Systems for giving me the opportunity to participate in this program. Also I am grateful for all of the help and patience given to me by Frank Fair and for all of the knowledge I gained from him. I also willingly received a lot of much needed help from Sgt. Darryl Zinzow and Peter George.

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

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Universal Energy Systems, Inc.

FINAL REPORT

CHEMICAL VAPOR DEPOSITION (CVD) ON CARBONACEOUS MATERIALS

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Date:	16 Sept. 88
Contract No.:	F49620-88-C-0053

CHEMICAL VAPOR DEPOSITION (CVD) ON CARBONACEOUS MATERIALS

by

Melissa M. Rose

ABSTRACT

In an attempt to prepare carbon-carbon composites using Chemical Vapor Deposition (CVD), several carbons were exposed to a mixture of 10% CH_4 and 90% Argon at isothermal tenperatures between 1000°C and 1100°C. The differences in the CVD rates were sufficiently large enough to warrant further investigation and discussion. The higher the temperature was, the higher the CVD rate became. A general trend was also observed with different activated samples of one carbon substrate (Graphon). As the burn-off level increased, so did the rate of CVD. These results combined to provide the following general explanation for the mechanism of the CVD process. When the substrates are exposed to the gas mixture, the C-H bond breaks, and pyrolytic carbon deposits on the surface with the liberation of the hydrogen gas. If the substrate has a small surface area (BET area and active surface area; ASA), e.g. carbon fibers, most of the cracking takes place in the gas phase. On the other hand, with substrates having larger BET and ASA values, e.g. V3 and V3G, the surface has a considerable effect on catalyzing the deposition, and the activation energy drops from the normal value of ~100 to 58 kcal/mole.

ACKNOWLEDGMENTS

I wish to extend my appreciation to the Air Force Systems Command and to the Air Force Office of Scientific Research for their sponsorship of my research project. My gratitude also goes to Universal Energy Systems , Inc. for giving me the opportunity to gain knowledge and experience in the "working world".

I would also like to thank my mentors, Mr. Les Tepe and Dr. Wesley Hoffman for their support and encouragement throughout the summer. The effort expended by Mr. Wayne Roe and Mr. Dick Clark is greatly appreciated, also.

I would especially like to thank Dr. Ismail M.K. Ismail for the time and energy he spent working with me for the past two summers. I will value his support and criticism for the rest of my college and professional career.

I. INTRODUCTION:

In the broad field of rocket nozzle technology, one matter has been of particular importance to the Air Force: carbon-carbon composites. These composites, composed of carbon fibers and a matrix, must be prepared efficiently and inexpensively, but they must be reliable and heat-resistant.

One way to prepare a carbon-carbon composite is by coal-tar pitch impregnation. In this process, carbon fibers are first impregnated with a coal-tar pitch (matrix) and then run through several cycles of carbonization (up to 1000° C) and graphitization (up to 2500°C), until a satisfactory non-porous composite is formed (density: 1.9-2.1 g/cc).

Another way to prepare carbon-carbon composites is through the chemical vapor deposition (CVD) process onto a carbon fiber. The main idea in this process is to expose a carbon fiber to a hydrocarbon gas (CH_4, for example) at high temperatures. From the thermal cracking of the hydrocarbon gas, pyrolytic carbon deposits on the fiber surface, thereby forming a matrix. This process is advantageous to the coal-tar-pitch process because one can control the rate of composite formation by changing the gas composition and flow rate or the reaction temperature. As a consequence, one can also control the rate and yield of reactions and properties of the final product through the CVD process. However, the most important advantage the CVD process has over coal-tar pitch impregnation is that CVD yields a high density product ($\sim$ 2.0 g/cc) which is close to that of natural graphite, the most stable carbon on earth (e.g. SP-1 GRAPHITE).

Because of these advantages, the CVD process has been the focal point of my research for the past two summers and Christmas breaks. The

majority of this summer was spent on confirming the results of my work last summer with Dr. Ismail, repeating some of the data that has been generated in the lab during the past two years, and other miscellaneous lab-related work. The results I obtained contributed to an ongoing experimental project done under a 5-year AFOSR contract.

II. OBJECTIVES OF THE RESEARCH EFFORT:

Although the process of Chemical Vapor Deposition allows one to control the rate and yield of composite formation, and is in many ways more advantageous than coal-tar pitch impregnation, CVD is surprisingly a relatively unexplored field and little has been published in the open literature on CVD on carbon fibers. Dr. Ismail, Dr. Hoffman and I, therefore, have been taking it upon ourselves to look into this process more closely.

The first goal of this research was to see how different temperatures under the same flow conditions and gas composition affected the rate of CVD on a certain carbon fiber and other carbonaceous materials. The four basic temperatures used were 1000°C, 1025°C, 1050°C, and 1075°C. The 25°C difference between each of the ascending temperatures was sufficient to cause quite a noticeable difference in the CVD rate for most of the carbons studied.

The second goal was to observe the differences in CVD rate on different carbonaceous surfaces. By observing these differences, we could propose a the mechanism for the CVD reaction: either by the cleavage of the carbon-hydrogen bonds of the hydrocarbon in the gas phase through the energy created by the high temperatures, or by the surface of the carbonaceous material enhancing (catalyzing) the breaking of the C-H bonds.

III. EXPERIMENTAL:

A. Materials

The materials used in this research project are listed in Table 1. SP-1 graphite (purified natural flakes), supplied by the Union Carbide Corporation, is known to have few ppm impurities; it is a non-porous carbon having a high density, 2.265 g/cc, which is very close to the theoretical value of 2.268 g/cc. Graphon, supplied by the Cabot Corporation, was prepared by graphitizing its precursor carbon black, Spheron-6, at 3000 K for two hours. The as-received Graphon is non-porous, but it has a helium density of 1.92 g/cc and an x-ray density of 2.18 g/cc. Two portions of Graphon were activated at 923 K in a muffle furnace with circulating air until the levels of 10% and 30% burn-off (B.O.) were reached. The V3G, another non-porous carbon black supplied by the Cabot Corporation, was prepared by graphitizing its precursor, Vulcan-3 (V3). Sterling MT is a third graphitized carbon black but it has a smaller BET surface area than Graphon and V3G. The VSB-32, supplied by the Union Carbide Corporation, is a graphitized petroleum pitch fiber (helium density 2.113 g/cc). The WCA fabric, supplied by the Fiberite Corporation in 1986 (lot #343), is a rayon fabric that has been heat treated at about 2700 to 2900 K, but the fabric is known to be a nongraphitic material with a density of 1.46 g/cc. The T-300 is a polyacrylonitrile (PAN) carbonized fiber which has been used extensively in fabricating several A.F. rocket nozzles.

B. Procedure

The rates of CVD were determined using a microbalance to record the amount of weight gain of a particular carbonaceous material as a function of time. The apparatus as pictured in Fig. 1 (a Thermogravimetric Analyzer; TGA)

was used. A small sample of known weight (from 5-40 mg) was suspended from the balance inside a flow reactor. The sample was first evacuated for 30 minutes and flushed with argon at atmospheric pressure. The system was then heated at a rate of 20 C /min. to 1000°C, 1025°C, 1050°C, or 1075°C (in one case, 1085°C) in an inert gas (argon) at a flow rate of 200 cc/min.. After the high temperature had been reached and the balance output became stable, the system was held under these conditions for 30 minutes. The hydrocarbon gas (a mixture of 10% CH_4 and 90% argon) was then introduced to the system to replace argon at the same temperature but a flow rate of 150 cc/min.. Depending on the nature of the material, the increase in sample weight was monitored for a predetermined length of time (3 hrs. to 20 hrs.). An IBM-PC computer recorded sample weight and temperature as a function of time; either every 15 seconds for the 3 hr. runs or every minute for the 20 hr. runs.

A plot of % weight gain vs. deposition time was subsequently made and the rates of CVD was determined by calculating the slopes of lines or regions. In some cases, depending on the type of sample or deposition temperature, the entire plot came out as a one linear region. In fewer cases, however, deviation from linearity was observed; there was either two linear regions intersecting at a specific yield, or one linear region followed by a region of a declining CVD rate.

IV. RESULTS AND DISCUSSION:

Four main effects on the rate of Chemical Vapor Deposition were investigated: 1) the effect of different carbonaceous substrates, 2) the effect of surface activation of one substrate, 3) the effect of sodium, and 4) the effect of temperature.

A. The effect of different carbon substrates on CVD:

Figure 2 shows the dependence of CVD yield on contact time at 1025° C. When each of three fibers was exposed to a 10% CH_4/90% Ar gas mixture under the same flow rate, the order of deposition rates was T-300 fiber (highest), WCA fabric (middle), and VSB-32 fiber (lowest). In general, the CVD rates should be somewhat affected by the surface area of the material (BET area, Active Surface Area, geometric surface area, or perhaps a combination of these areas). Although the WCA fabric has the highest BET surface area, its rate is midway between the two other fibers. Selected results that have been obtained at AFAL over the past 3 years and the data obtained during the summer are shown in Figure 2 and summarized in Table 2. The second column in Table 2 lists values of CVD rates obtained by calculating the slopes of the lines in Figure 2. The BET surface areas and the Active Surface Areas (ASA) were taken from Ref. 1 and 2, (the third and fourth column). The last two columns contain values for the CVD rates normalized to the surface areas (BET and ASA). It is observed that the rates of deposition cannot be normalized either to the total surface area or to oxygen-active surface area. There is one possible explanation for this, which is beyond the scope of this work: the geometry factor. In other words, each of these materials has a certain diameter which is different than the other materials. The bundles of T-300 and VSB-32 fibers have 3000 and 2000 filaments, respectively. The WCA fabric is not composed of loose bundles, but it is weaved in a certain way: both in warp and fill directions.

B. The effect of surface activation on CVD rates:

Now, we consider one material (Graphon) when activated to two different levels of burn-off (B.O.): 10% and 30% (Figure 3). It is seen that as the material is activated to higher levels of B.O., the deposition rates slightly increase because both the BET and active surface areas have been increased prior to the deposition as a result of B.O. (Ref. 3). However, the increase in deposition rates once again cannot be normalized to either the BET or the active surface areas. For example, as Figure 3 shows, increasing the B.O. from 0% to 10% does not significantly increase the deposition rate although it does increase the ASA by a factor of 8 from 0.26 to 2.10 m^2/g and the BET surface area from 76 to 105 m^2/g. From these limited data it is apparant that surface treatment of a carbon substrate prior to deposition does not have a dramatic effect on increasing the CVD rate.

C. The effect of sodium:

It is known that sodium, as well as other cations (K, Mg, Ca, etc.), are excellent catalysts for many heterogeneous reactions (Ref. 4). It was then thought that Na may as well be an excellent catalyst for the CVD reaction. To decide on a material for this particular study, none of the carbons listed in Table 1 could be used because they all have very small Na concentrations. The most appropriate materials for this study were two carbonized rayon fabrics which have very similar properties but different amounts of Na: CCA-3 1641B (13 ppm of Na) and CSA 4671 (3152 ppm Na). Figure 4 shows the dependence of CVD rates on Na content of materials. Although there is a slight increase in the rates

with the increase in the Na content, the observed catalytic effect is negligible. This might suggest that cations do not substantially contribute to the CVD reaction, and that the mechanism of CVD is not primarily influenced by the presence of a catalyst.

D. The effect of temperature on CVD:

The deposition rates between 1000°C and 1100°C were examined on several materials: VSB-32 (Ref. 5), SP-1 Graphite, Sterling MT, V3, V3G (0% B.O.), and V3G (30% B.O.). Generally, increasing the temperature is associated with an enhancement in deposition rates (Figure 5). For VSB-32 fiber, the plot shows one linear region up to 120% weight gain. With other materials, however, the plot was not linear. For example, Figure 6 shows that for Sterling MT at 1000°C the rates at the beginning of the exposure to methane are slow and then attain a constant value after one hour. At 1050°C, the rate is almost linear from the beginning of exposure. At 1075°C, however, there are two distinct linear regions which intersect at about 95 % weight gain. A similar trend was also observed with some other graphitic materials (e.g. V3G) where it was noted that the break at different temperatures occurred after a certain fixed weight of pyrolytic carbon was layed down on the substrate. This probably indicates that the deposition starts on the external surface of the particles and after a given build-up, the deposition continues on the newly developed surface. In other words, the break is mainly attributed to a change from a deposition on the substrate to a deposition on pyrolytic carbon.

By taking the slope of the linear region obtained at 1000°C and 1025°C and the slope of the first linear region obtained at 1075°C, the Arrhenius plots (Figure 7) were constructed. The data in the figure can be summarized as

follows: 1) at a given temperature, the deposition rates on VSB-32 fiber are the lowest, 2) the rates on V3 and V3G, which have the highest BET surface areas, are the highest, 3) the rates on Sterling MT and SP-1 Graphite are in between the lowest and the highest rates, 4) the rates on the carbonized material (V3) are slightly higher than the rates on the graphitic material (V3G), and 5) The energies of activation (E_a) of the reaction are primarily dependent on the type of substrate. Table 3 summarizes the values of E_a on different carbons. At one extreme, the E_a of VSB-32 fiber and Sterling MT are high (92-98 kcal/mole). At the other extreme, the E_a for V3 and V3G are low (58 kcal/mole). The SP-1 sample seems to indicate a peculiar behavior because E_a is extremely high (143 kcal/mole). Additional tests are required to be performed on this sample to explain this phenomenon. The high value of E_a means that the mechanism of CVD on these samples, which have low surface areas (less than 10 m^2/g), is controlled by the rupture of the C-H bond in the hydrocarbon gas (Ref. 6). The mechanism of CVD with V3 and V3G is quite similar to that observed with Graphon (Ref. 7,8). The large value of surface area, especially the active surface area, enhanced the rates of cracking of the hydrocarbon molecules on their active sites. That is, the materials which have high ASA were catalyzing the rupture of the C-H bond.

V. Conclusions:

The rate of Chemical Vapor Deposition, at a constant gas composition and flow rate, is dependent on three factors: 1) reaction temperature, 2) type of substrate used, and 3) type of surface treatment (activation) prior to the deposition. The sodium content in a carbon substrate seems to have little effect on the rate or yield of CVD. The activation energy of different carbon substrates

helps to explain the mechanism of deposition. If the substrate has a high surface area (BET and ASA), the activation energy is low, and the C-H bond in the hydrocarbon gas will break after colliding with the surface of the substrate. In other words, the surface has a catalytic effect on the cleavage of the C-H bond. By contrast, if the substrate has a low ASA or BET surface area, E_a is high and approaches the C-H bond energy (98 kcal/mole), i.e., the energy required to separate carbon from hydrogen atoms. Thus, the rupture of the C-H bond takes place in the gas phase before reaching the surface of the substrate and is the rate determining step.

VI. RECOMMENDATIONS:

The Thermogravimetric Analyzer is a powerful tool for establishing the effect of different experimental parameters (gas composition, flow rate, reaction temperature, type of substrate, and inhibitors) on reaction rates and yields. However, the weights of the carbon-carbon composites, prepared during the course of this work, were very small (10-15 mg) and the samples could not be used for further testings. Therefore, a larger reactor should be used to prepare sizeable composites that could be used for further testings and examinations. These include SEM and TEM examination to study the topography and morphology of deposits, density and porosity measurements to assure the preparation of a reliable end product, and surface area measurements to address the problem of rocket nozzle erosion.

Since I have gained a considerable amount of valuable experience working on this project during the past two summers, I would sincerely like to ask for the same opportunity in the summer of 1989 to continue my contribution to this project.

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TABLE 1: Surface Area and Density of Carbons

Material	BET Surface Area (m^2/g)	Density (g/cc)
SP-1 Graphite	1.98	2.265
Graphon:		
0% B.O.[(a)]	82.2	1.92[(b)]
10% B.O.	105.0	NA[(c)]
30% B.O.	123.0	NA
V3	71.0	NA
V3G	59.2	NA
Sterling MT	9.1	1.98[(b)]
VSB-32	0.54	2.113[d]
WCA	0.66	1.46[d]
T-300	0.56	1.83[d]

(a) Burn-off
(b) literature values
(c) Not available
(d) From reference #1

TABLE 2: Rates of Chemical Vapor Deposition normalized to starting sample weight, BET Surface Area, and Active Surface Area.

Material	Deposition Rate mg/g/min	Surface Area (m^2/g) BET*	0_2-ASA*	RATE BET ($mg/m^2/min$)	RATE ASA ($mg/m^2/min$)
T-300 Fiber	0.644	0.56	0.075	1.15	8.59
WCA Fabric	0.500	0.66	0.068	0.78	7.30
VSB-32 Fiber	0.429	0.54	0.029	0.79	14.7

* BET Surface area determined by gas adsorption at 77 K (References # 1 and 2)
** Active Surface area determined by oxygen chemisorption (Reference #1)

TABLE 3: Comparison between Surface Area of Carbons and their Corresponding CVD Activation Energy.

Material	BET Surface Area (m^2/g)	Activation Energy (kcal/mole)
VSB-32	0.54	98
SP-1 Graphite	1.98	143
Sterling MT	9.10	92
V3G	59.2	58
V3	71.0	58

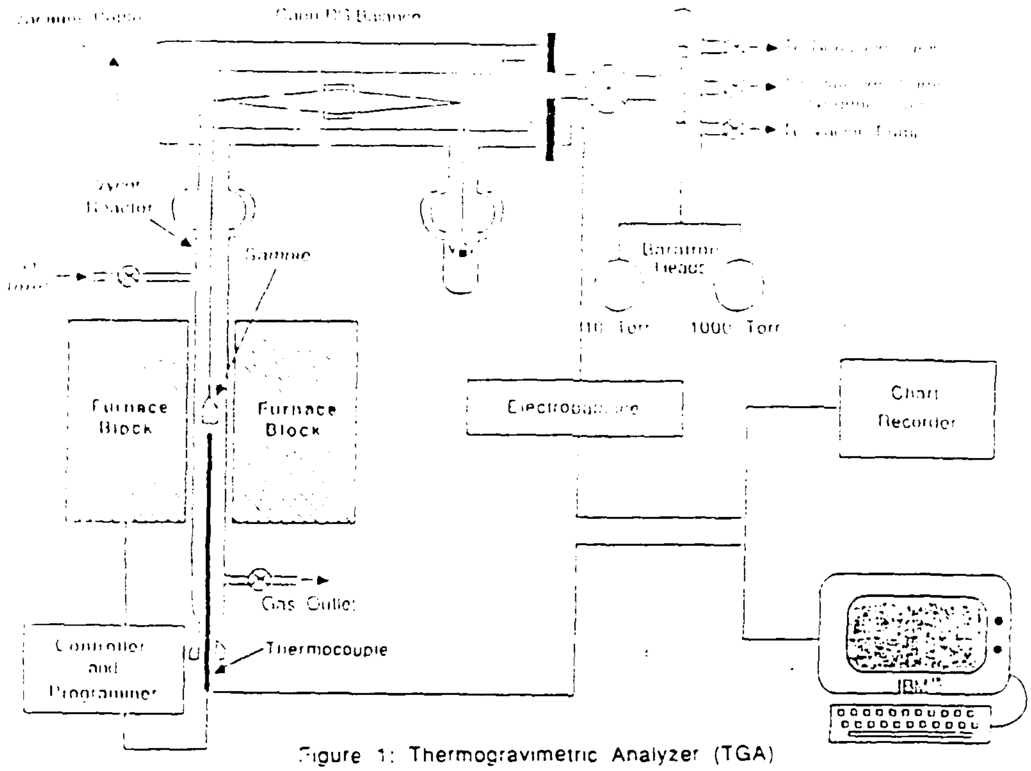


Figure 1: Thermogravimetric Analyzer (TGA)

Figure 2: Different Carbon Substrates at 1025 C

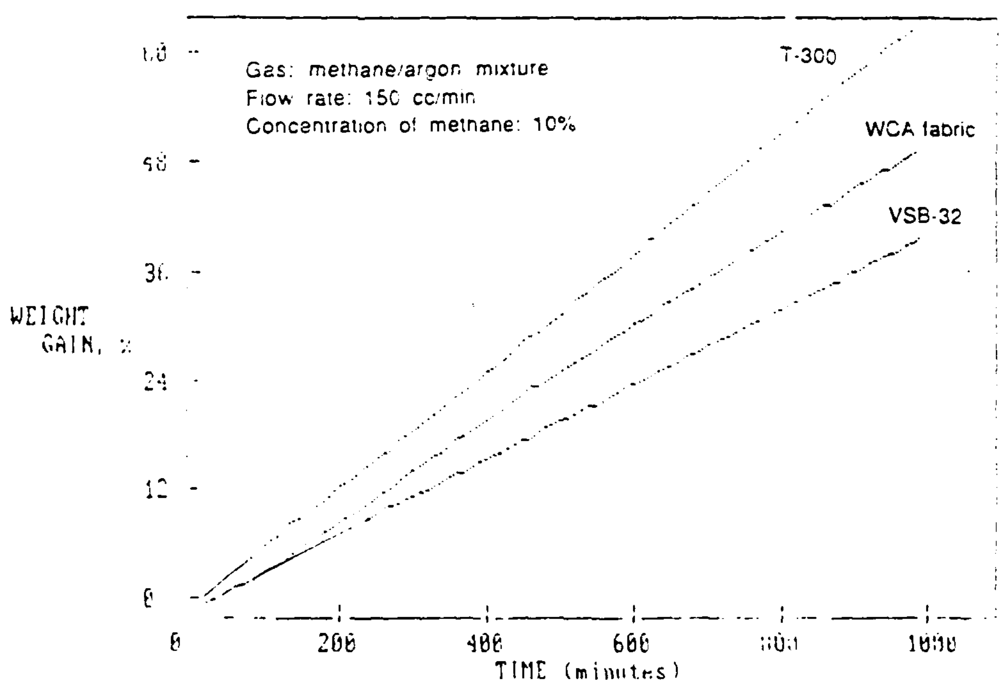


Figure 3: Graphon- The Effect of Surface Activation on the CVD Rate

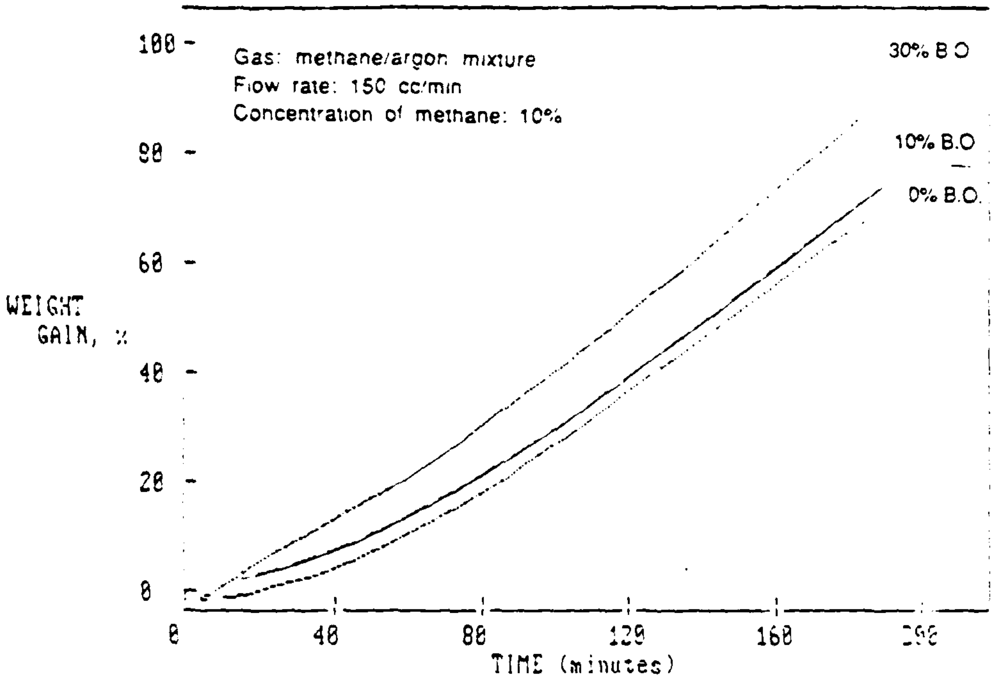
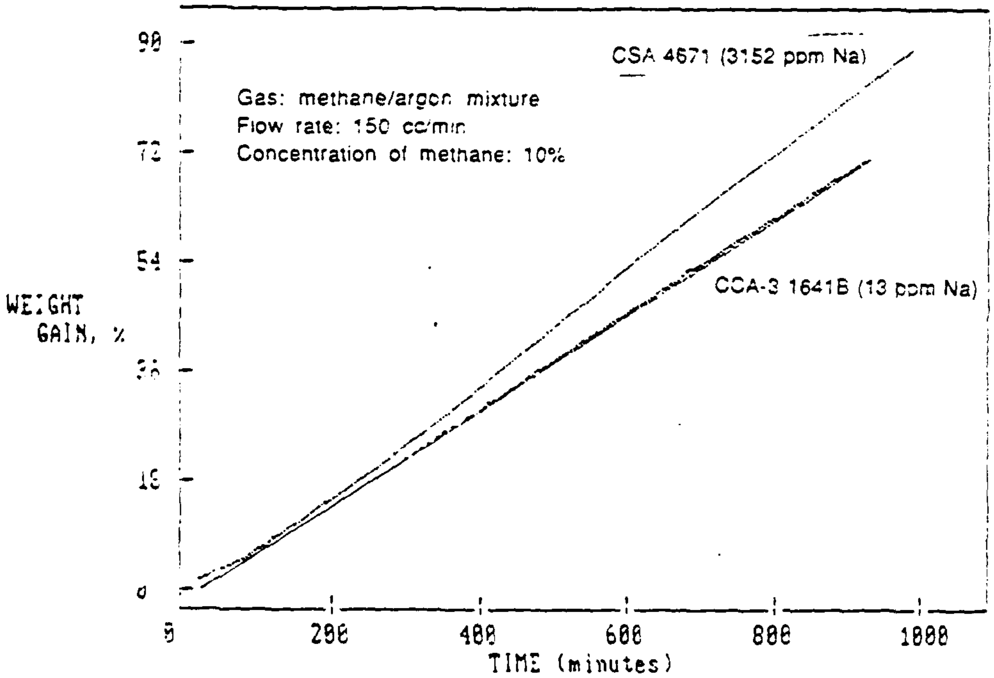


Figure 4: The Effect of Sodium on the CVD Rate



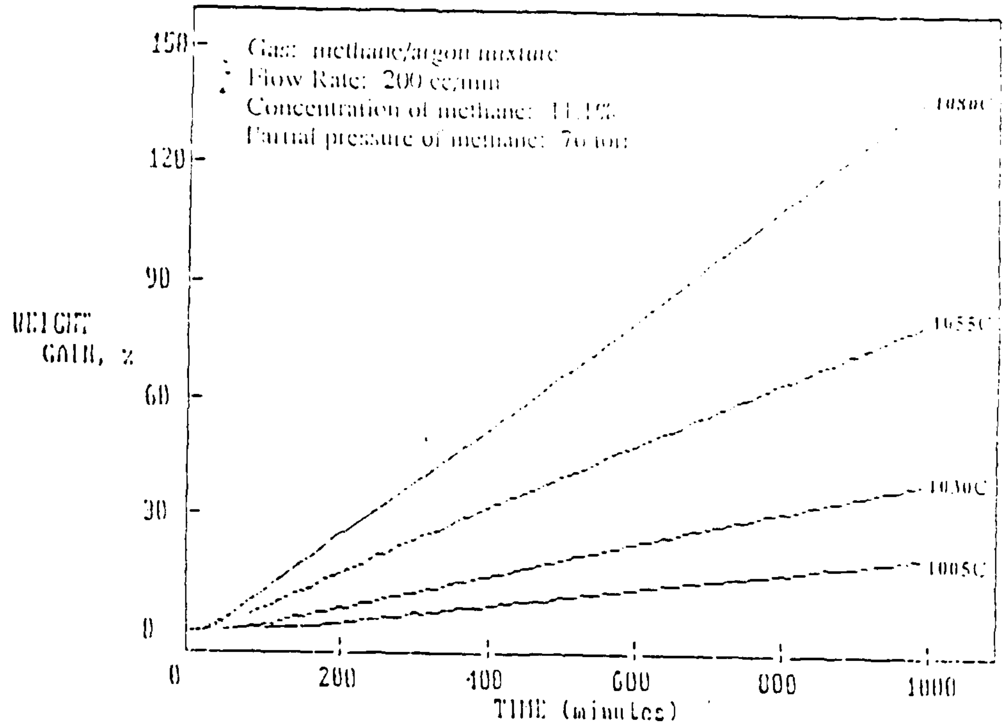


Figure 5: Typical thermograms for methane cracking over VSB-32 fiber (flow system).

Figure 6: Sterling MT

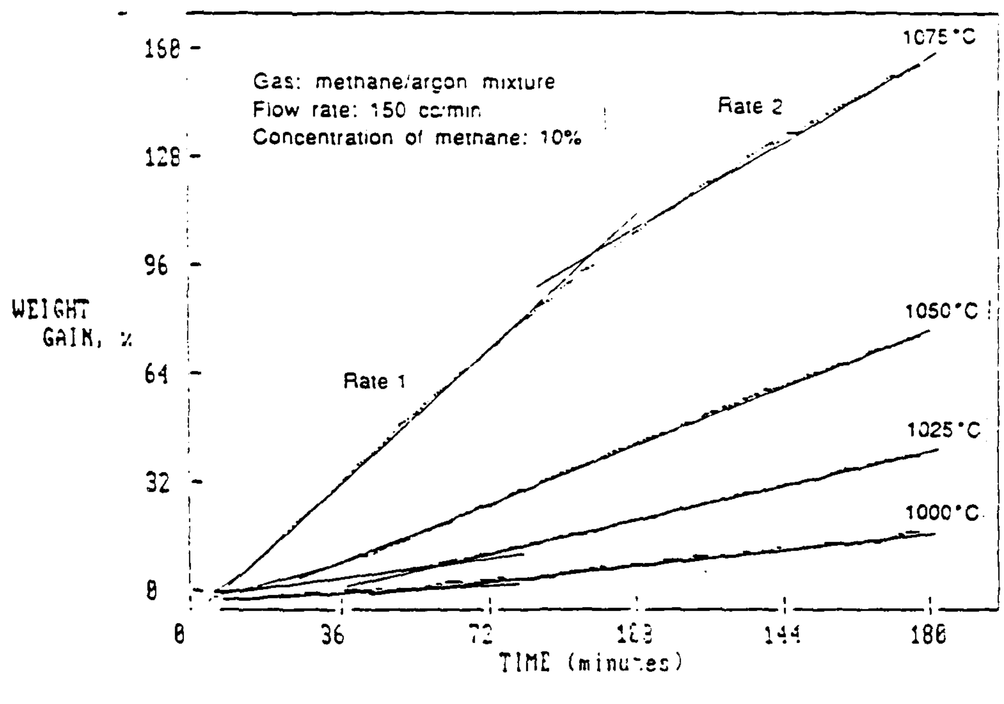
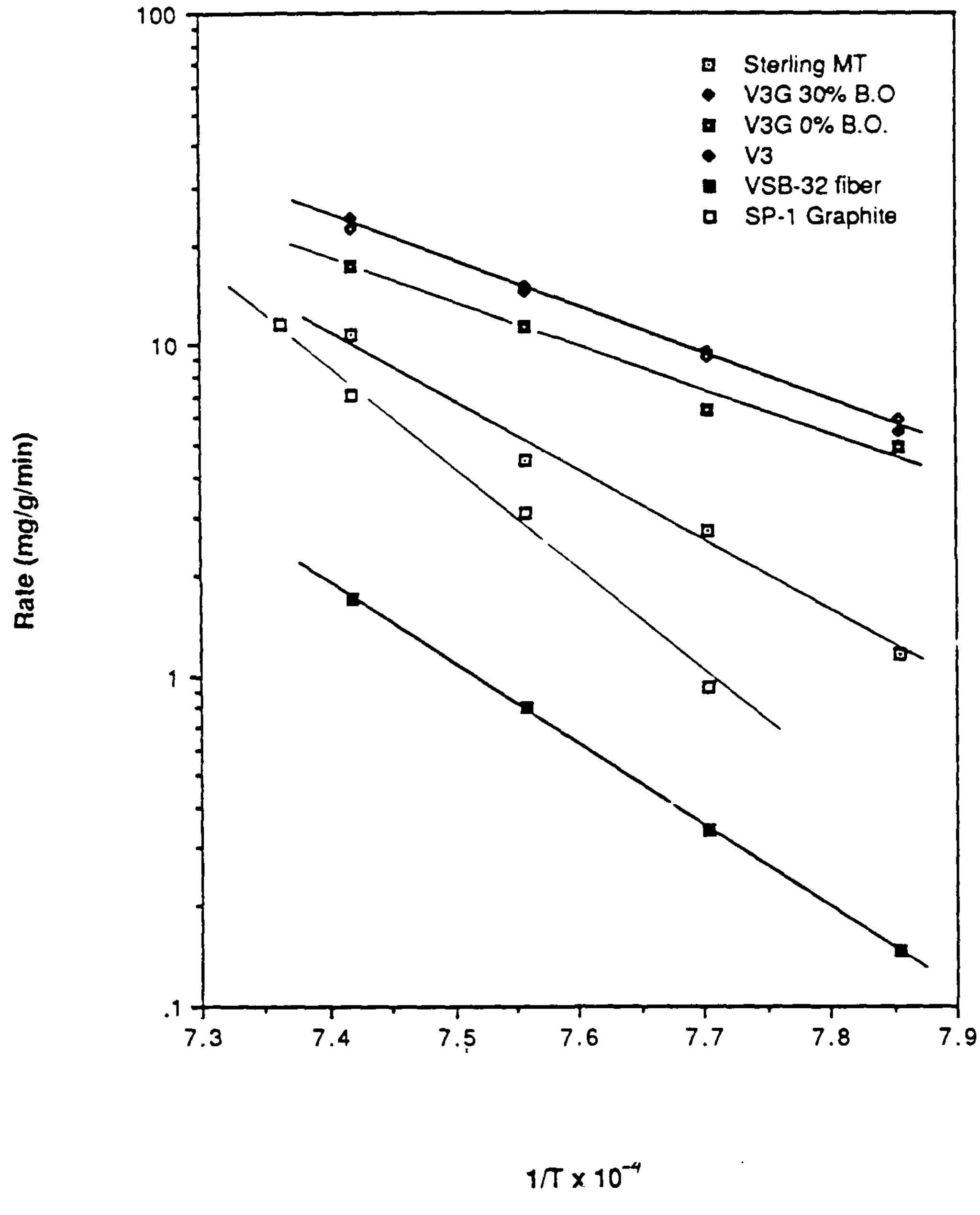


Figure 7: Arrhenius Plot



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FINAL REPORT

DATA ANALYSIS AND MANIPULATION FOR THE KINETIC KILL VEHICLE HOVER INTERCEPTOR TEST

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Research Location: Air Force Astronautics Laboratory, Vehicle Systems Division, Integration and Analysis Branch

USAF Researcher: Mr. Dave Ductor

Date: August 15, 1988

Contract No.: F49620-88-C-0053

DATA ANALYSIS AND MANIPULATION FOR THE KINETIC KILL VEHICLE HOVER INTERCEPTOR TEST

by

Natalie Beth Stubbings

ABSTRACT

As a 1988 Summer Fellow in the College Science and Engineering Program through Universal Energy Systems, Inc., I was privileged to work on the portion of the Strategic Defense Initiative known as KHIT. The KHIT, or Kinetic Kill Vehicle Hover Interceptor Test, represents a design for a Kinetic Energy Weapon. During the course of the summer portions of the KHIT system were tested. I aided the manipulation and analysis of test data by transferring informa on between computer systems and studying temperature measurements. I also participated in two presentations. These were given to co-workers, company representatives, and fellow students.

I. INTRODUCTION:

The study of Kinetic Energy Weapons (KEW's) is currently in progress at the Air Force Astronautics Laboratory. Weapons of this type are being developed for strategic defense as possible countermeasures against intercontinental ballistic missiles. In general, the KEW will be launched from the ground or an orbiting platform using a rocket booster. The KEW will then use its own propulsion and guidance systems to locate, intercept, and destroy intercontinental ballistic missiles.

One design for a KEW is currently being studied in the laboratory's Vehicle Systems Division under the Kinetic Kill Vehicle Hover Interceptor Test (KHIT) program. The KHIT vehicle has been designed, and has undergone three static tests. The information gathered from these tests is being analyzed, and applied toward future testing and vehicle modification. As a sophomore aerospace student, I was assigned to the vehicle systems division to assist with this data analysis for the KHIT vehicle.

II. OBJECTIVES:

During my employment as a 1988 College Science and Engineering Program Summer Fellow I was assigned to various projects relating to the KHIT vehicle. Each task I performed was intended to achieve certain goals which were determined during the course of my work. Each project centered around some aspect of a test firing of the KHIT vehicle. The projects, and their corresponding objectives, are as follows:

I. BASIC KHIT KNOWLEDGE ACQUISITION

Goal: To familiarize myself with the KHIT vehicle, test program, and test facility.

II. KHIT STATIC TEST DATA MANIPULATION

Goal: To transfer static test data from one computer storage location to a separate computer cluster in in order to utilize an application of the cluster.

III. COMMUNICATION OF KHIT PROGRAM AND TEST RESULTS

Goal: To inform co-workers and Summer Fellows of the status of the KHIT program and the results of the static test firing.

IV. KHIT MISSION DUTY CYCLE TEST DATA ACQUISITION AND ANALYSIS

Goal: To transfer temperature data from one computer storage system to a separate computer cluster, utilize an application of that cluster, and draw conclusions from the data.

V. COMMUNICATION OF MISSION DUTY CYCLE TEMPERATURE ANALYSIS RESULTS.

Goal: To communicate to co-workers the results achieved from the analysis of mission duty cycle temperature data.

III. APPROACHES AND RESULTS

1. Basic KHIT Knowledge Acquisition

For my first assignment in the Vehicle Systems Division I was asked to familiarize myself with the KHIT program. The most valuable source of information on KHIT was the knowledge of the engineers who were working on the vehicle. These people described the program, answered questions, and provided documentation on KHIT. The material provided included various technical memorandums, video tapes of past tests, and general program organizational outlines. In addition, visits to the KHIT test site provided a closer look at the vehicle and test facility. A basic overview of what I learned follows, and provides an introduction to the KHIT program.

As part of the Kinetic Energy Weapon portion of the Strategic Defense Initiative the Astronautics Laboratory is conducting the Kinetic Kill Vehicle Hover Interceptor Test (KHIT). The vehicle being tested is designed to be propelled from a space or ground based source at a velocity of 10 kilometers per second. It will then track, aim for, and intercept an intercontinental ballistic missile. The vehicle is equipped with a seeker, built by Martin Marietta: an avionics system, built by Autonetics; and an eight engine propulsion system, built by Rockwell International. The Air Force Astronautics Laboratory is responsible for the testing and integration of the various vehicle components. As part of this testing an existing Air Force test facility was modified for KHIT by Wyle Laboratories.

The KHIT program incorporates five tests of the vehicle. On November 10, 1987, the first of the five tests occurred. This was the Drop Test, where a model vehicle was dropped from various heights in order for the Astronautics Laboratory to test a telemetry system. The second test, on July 8, 1988, involved the firing of each of the eight engines for one second pulses. This Facility Activation Test verified the performance of the propulsion system, as well as the operability of the test facility. The third test was the Mission Duty Cycle test of July 21, which simulated the propulsion cycle for an actual mission of the vehicle. The firing lasted 28 seconds, and incorporated seven of the eight engines. The last two tests have not been conducted yet. They include a hover test, where the vehicle will hover in free flight, and an ON-TARGET test, where the vehicle will hover while tracking a rocket exhaust plume. These tests are tentatively scheduled for October, 1988 and early 1989, respectively.

II. KHIT Static Test Data Manipulation

My first major task as a Summer Fellow was to help two other students manipulate the data from the Facility Activation Test. During this test of the Kinetic Kill Vehicle Hover Interceptor Test (KHIT) vehicle data was obtained regarding the health of the vehicle. This data was taken using two different systems, the Labview and MacADIOS Macintosh applications. Once taken, the data had to be modified to obtain decipherable and useful information. This was done by transferring the Labview and MacADIOS measurements onto a VAX computer and producing graphs with a Matrix-X plotting application. The following process was used:

The Labview and MacADIOS data was stored on a hard disk at the test site, transferred to 3.25" floppy disks, and copied onto a hard disk in the Integration section. The floppy disk data from Labview was transferred directly to the VAX, but the MacADIOS information was incompatible with the VAX. Therefore the MacADIOS data was reformatted and then transferred to the VAX cluster. Both the Labview and MacADIOS measurements were placed in various accounts on the VAX, and one copy of the data remains on a hard disk in the Integration section of the Vehicle Systems branch. The transfer of data from the Macintosh to the VAX was accomplished using the Kermit application.

The purpose of placing the KHIT data into the cluster was to allow the use of the VAX interactive software, Matrix-X. Matrix-X is capable of handling data in matrices, the manner in which the KHIT measurements were stored. However, this information was not in a form that Matrix-X was able to decipher. Both the Labview and the MacADIOS matrices had to be assigned to a variable, and extra characters in the Labview data were removed. Once both sets of data were properly formatted, Matrix-X was used to produce various graphs for analysis. In order to better understand the graphs, some were either filtered or put through a Fourier transform. These graphs were then analyzed by other individuals involved in KHIT data processing.

III. Communication of KHIT Program and Test Results

Near the completion of static test data manipulation, the mission duty cycle firing occurred. As part of the Summer Fellow program I was asked to give a briefing on this firing, the static test results, and the KHIT program in general. The purposes of this speech were to advise other students of the KHIT program, inform co-workers of the results of the static and mission duty cycle tests, and gain experience in public speaking. The material that was to be covered was divided up among myself and three other students, and I chose to speak about the three past KHIT tests and the test facility. The topics covered by the other three students included KHIT's role in the Strategic Defense Initiative, the hardware and specifications of the vehicle, and the future plans for system testing.

IV. KHIT Mission Duty Cycle Test Data Acquisition and Analysis

The Mission Duty Cycle test performed on July 21, 1988 provided data on the status of various portions of the KHIT vehicle and test facility. Part of this data included temperature measurements for the vehicle surface, internal systems, and engine exhaust plume. Due to my interest in heat transfer and fluid flow I was asked to obtain and analyze the plume temperature data. This analysis was necessary in order to verify that the containment net, which will protect the test facility during a hover test, would survive the heat of the engine plume. A sample of the netting had been shown to disintegrate when reaching a temperature of 2,200 degrees Fahrenheit for a period of four seconds.

The data was obtained using four thermocouples: one placed directly on the engine nozzle, and three in the air at varying

distances from the nozzle. Measurements were taken to determine the exact location of the thermocouples in relation to the vehicle and test stand. Temperature measurements from the engine firing were transferred from floppy disk onto the VAX cluster, and a Fortran program was created to remove unrelated data points from the original set of data. Once the measurements were in a form that was understandable by the Matrix X application, graphs were made of thermocouple temperature versus time. A summary of the results follows:

RESULTS: Highest temperatures - 960 degrees F.
1' 3.5" from nozzle end
t=14 seconds into test

800 degrees F.
2' 11" from nozzle end
t=3 &13 seconds into test

510 degrees F.
9' 6" from nozzle end
t=17 seconds into test

1,950 degrees F.
on nozzle
t=28 seconds into test

V. Communication of Mission Duty Cycle Temperature Analysis Results

Information gathered regarding the engine exhaust plume temperature was relayed to KHIT project co-workers during a briefing on July 29, 1988. Representatives from the Astronautics

Laboratory, Autonetics, Rockwell, and Wyle Laboratories attended the meeting. The purpose of the meeting was to allow the exchange of Mission Duty Cycle data, and to use this data to plan for future KHIT test improvements.

To effectively communicate the results of the plume temperature analysis, I first explained the purpose of the analysis. I then displayed a diagram which showed where each of the four KHIT thermocouples were located in relation to the divert #1 flame trough. Finally, graphs of temperature versus time for each of the thermocouples were shown individually, as well as one graph showing all four thermocouple readings versus time. The final conclusion, that the containment net would not burn through under conditions similar to the Mission Duty Cycle test, was then discussed.

IV. RECOMMENDATIONS

II. KHIT Static Test Data Manipulation

The Matrix-X graphs describing the results of the KHIT Facility Activation Test were helpful in two ways. They aided the analysis of the test firing, as well as providing information regarding the methods by which the data was taken. The measurements obtained were used to evaluate the performance of the KHIT vehicle, and should be retained for future reference. The success of the data acquisition system was proven, and a similar system analysis should be undertaken after each of the upcoming vehicle tests.

III. Communication of KHIT program and Test Results

As a result of the presentation given to fellow summer employees, these students learned about an area of the Astronautics Laboratory that they did not work in. The speech also allowed four Summer Fellows to gain experience in public speaking. Presentations of this nature should be encouraged among summer students.

IV. KHIT Mission Duty Cycle Test Data Acquisition and Analysis

In order to insure the safety of the KHIT vehicle and test facility during the two upcoming tests, I recommend that the firing time of a divert engine be limited to the amount of time that divert #1 was fired during the Mission Duty Cycle Test. This recommendation is based on the fact that a sample of the containment net, which will protect the vehicle and test facility, disintegrated when exposed to a 2,200 degree Fahrenheit propane torch for four seconds. The following data from the Mission Duty

Cycle test shows that there is a possible danger to the net if a single divert engine fires for an extended length of time.

The highest temperatures recorded during the test were located on the throat of the divert #1 nozzle. A maximum temperature of 1,950 degrees Fahrenheit was measured approximately 27 seconds into the test. If a divert engine fires for a longer time span than that of the Mission Duty Cycle the throat temperature would probably exceed 2,200 degrees. If this occurs, and the engine touches the net, then a burn through of the net could result. The throat cooled quickly after the engine stopped firing, decreasing 800 degrees Fahrenheit in approximately 1 second. Therefore, the net should be able to withstand the throat temperature if the engine stops firing and then contacts the net, since the throat cools rapidly. As a result, the length of the hover test should be limited by the total engine firing time of a divert engine.

V. Communication of Mission Duty Cycle Temperature Analysis Results

The briefing of July 29, 1988 illustrated the results of the Mission Duty Cycle Test data analysis. This allowed for the exchange of information between the various organizations involved in KHIT. The briefing was informative and helpful, since some of the shared information was relative to future test procedure. I recommend that meetings of this type be held more frequently as the KHIT testing becomes more complex. I also recommend that the suggestions made at the briefing regarding controversial subjects be followed, or the subjects be studied more thoroughly.

ACKNOWLEDGEMENTS

I would like to express my appreciation for the assistance of the following individuals and organizations, without whom this research effort could not have been undertaken:

Universal Energy Systems, Inc. for providing me the opportunity to be a part of the College Science and Engineering Program.

The Air Force Office of Scientific Research, Air Force Systems Command, and the Air Force Astronautics Laboratory for providing me with a facility to work in and research to accomplish.

Mr. Dave Ductor and Mr. Dave Barnhart of the Vehicle System branch for their technical advice, guidance and support.

Mr. Richard Clark of the Astronautics Laboratory for acting as my contact between Universal Energy Systems and the Air Force.

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

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FINAL REPORT

Integrated Test Facility Activation for Hover Testing Kinetic Kill Vehicles

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Contract No.:	F49620-88-C-0053

ACKNOWLEDGMENTS

I wish to thank the Air Force Systems Command, the Air Force Office of Scientific Research, and the Air Force Astronautics Laboratory for sponsorship of this research, and Universal Energy Systems for administrating the College Science and Engineering Program. Special thanks to Wayne Roe and Richard Clark who coordinated the 1988 AFAL Summer Fellowship Program.

A special word of thanks is also due the staff of AFAL/VSAA for making my experience rewarding and enriching. In particular, Dr. Alan Weston, Brian McKee and Dave Ductor provided guidance, support and an enjoyable working atmosphere.

Deserving honorable mention are John Shimada, Roy Coats, and the crew of WYLE Laboratories for their cooperation and assistance.

Integrated Test Facility Activation For

Hover Testing Kinetic Kill Vehicles

by

Edward C. Tomlinson

ABSTRACT

The Kinetic Kill Vehicle Hover Interceptor Test (KHIT) program will establish an advanced test site at the Air Force Astronautics Laboratory (AFAL) for hover testing Kinetic Kill Vehicles (KKV) and evaluating their structural dynamics.

I. INTRODUCTION

The Air Force Astronautics Laboratory (AFAL) has been developing technology to resolve Kinetic Kill Vehicle (KKV) propulsion system issues as part of the Strategic Defense Initiative (SDI) program. Due to the hit-to-kill strategy associated with KKVs, one of the major issues is terminal end-game performance. Complex interactions exist between propulsion, structure, flight control, and guidance functions. In the presence of millisecond multi-gravity divert maneuvers, center-of-gravity offsets, hydrodynamics and other dynamic structural forces, there is valid concern that target seeker and guidance components may be significantly impacted by background disturbances caused by structural vibrations and rotations.

II. OBJECTIVES

To resolve these problems and demonstrate propulsion system/guidance and target tracking technology for Kinetic Energy Weapons (KEW), a controlled hot fire test must be conducted and data collected on the overall stability and dynamics of the KKV. The KKV must be tested and evaluated in an unrestrained hover test environment to ensure data fidelity. Therefore, an ambient facility must be designed and activated for the purposes of this testing.

III. FACILITY ACTIVATION

A facility for hover testing KKV's must have many support fixtures, including: propellant transfer and storage fixtures, laminar flow bench for vehicle servicing, center-of-gravity and moment-of-inertia machine for measuring pre-flight vehicle mass properties, and video monitors and recording equipment. These are just a few of the fixtures presently in place.

A computer controlled real-time data acquisition system was installed to monitor and record vehicle temperatures, pressures, valve driver voltages and currents. A telemetry system was acquired and installed for capturing in-flight instrumentation data. And a laser ranging/tracking system was being designed and tested in order to provide accurate position data for the ground computer system and navigation resets to the on-board inertial reference unit. Most of these components were successfully installed and integrated for the first vehicle static test firing.

IV. RECOMMENDATIONS

The United States Air Force Astronautics Laboratory is developing the most sophisticated facility for hover testing Kinetic Energy Weapons. Further utility will be realized when rocket plume target simulation generation and translation capability is added, and target tracking end-game performance can be fully measured, demonstrated and evaluated.

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FINAL REPORT

SUMMER WORK EFFORT

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Contract No :	F49620-88-0053

<u>SUMMER WORK EFFORT</u>

by

Simon Turner

<u>ABSTRACT</u>

In order to supplement the predominantly theory oriented education provided by Purdue University, I have pursued primarily 'hands-on' engineering work while working at the Air Force Astronautics Laboratory. This includes familiarization with various types of equipment and approaches used in practical research, helping with and running tests, and also the analysis of the acquired data.

I. INTRODUCTION

As a junior in Purdue University's School of Aeronautics and Astronautics, I am being exposed to a great deal of engineering theory right now. However, it is difficult to maintain a strong learning curve without continued motivation and a realistic idea of where that knowledge will lead. As my interests lie in the field of astronautics, primarily space structures, I decided that some practical work experience in that area would be beneficial. To this end, I accepted the contract offered by UES, Inc. to work at the Air Force Astronautics Laboratory in the Vehicle Systems Division.

In the Vehicle Systems Division, the VSSS group, to which I was assigned, is primarily concerned with in-house experimentation concerning large space structures in an effort to improve existing models and concepts in that field as well as put forward new ideas. Some of the concepts under investigation are general structural dynamics, modal identification, and applied control theory. The work being done here is intended to expand the United States' technological base in this area and will have an impact on programs such as future USAF space systems, NASA's proposed space station and the Department of Defense's ongoing Strategic Defense Initiative.

II. OBJECTIVES OF THE RESEARCH EFFORT :

As research in the field of large space structures is still in its infancy, a great deal of experimental work is necessary in order to provide a general understanding of the kind of behavior that is being dealt with. With this in mind, my initial goals in the VSSS group were to get a better idea of the experimental process as well as to gain an appreciation for the role played by the aerospace engineer in the real world. In addition to learning about the experimental approaches used, I also wanted to become familiar with the type of equipment that is used to gather and analyze data.

III. TYPE OF WORK DONE

The research that I was most closely involved with concerned the observation and analysis of the vibrational characteristics of a grid-type structure in an effort to gain some insight into the behavior that such a structure would be subject to in space. The vibrational characteristics of the excited grid were observed and recorded using accelerometers that were mounted on the grid and used to measure local accelerations. The accelerometer data was amplified, filtered and patched through to a real-time observer mini-computer where it was stored on hard disk to be uploaded to one ˜ the lab's larger computers for further analysis.

By taking part in this research, I became acquainted not only with the equipment, but with the manner in which it was used. The accelerometers were attached to different points on the grid structure which was suspended vertically. The accelerometers were powered by a constant current source and their signals were sent through a low-pass filter in order to filter out high frequency noise. The signals' gains were then amplified and routed to one of a number of data acquisition/analysis devices. Devices such as an oscilloscope or a dynamic signal analyzer were useful for providing a clear picture of the signal that was being received. The ISI MAX100 real-time control computer was useful for recording samples of data that were to be analyzed at a later date on one of the lab's VAX computers.

Once the accelerometer data was uploaded to the VAX, it was analyzed in an effort to determine the natural modes of vibration of the grid structure. This was done using MATRIXx software on the VAX. In MATRIXx, a sample of data is put into matrix form and can be manipulated easily. To identify the major frequencies of vibration measured, the data from each accelerometer was transferred from the time domain to the frequency domain using MATRIXx's capability to perform fast-fourier transforms. This data can

then be plotted, using MATRIXx, to illustrate it clearly. Once the primary characteristics of the grid structure have been determined, a model of the structure can be generated on the computer using NASTRAN and PATRAN to predict the structure's behavior under different conditions. As soon as a model is created, a control routine can be devised and tested on the grid.

IV. RECOMMENDATIONS

I have benefitted a great deal from this experience and would recommend that the UES CSEP program continue to encourage undergraduates to experience the real world of engineering in order to provide the motivation necessary to succeed in their chosen field of study.

ACKNOWLEDGEMENTS

I would like to acknowledge the Air Force Systems Command, Air Force Office of Scientific Research and the Air Force Astronautics Laboratory for their sponsorship of this program. I would also like to thank Dr. Alok Das for his patience and good humor.

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

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FINAL REPORT

MECHANISM OF CHEMICAL VAPOR DEPOSITION (CVD) ON CARBONS

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Contract No.:	F49620-88-C-0053

MECHANISMS OF CHEMICAL VAPOR DEPOSITION (CVD) ON CARBONS

by

Tamara Gwen Vass

ABSTRACT

To test the effectiveness of Chemical Vapor Deposition (CVD) in a static reactor, samples of SP-1 (natural graphite), activated to a 12.4% level of burn-off, were subjected to doses of methane at 1273 K. Active surface area measurements (using oxygen chemisorption techniques) as well as measurements of total surface area (using gas adsorption at 77 K were performed. Scanning electron micrographs of the end product were obtained. After examining the SP-1 CVD samples, it was found that when more than one ASA *equivalent* layer was deposited, the ASA of the original sample dropped form an initial value of 0.24 m^2/g to a constant value of 0.15 m^2/g. By contrast, the total surface area values kept decreasing. Based on this limited work, there are two possible mechanisms for CVD on SP-1 graphite, either a chaining mechanism where pyrolytic carbon repeats the ASA pattern of the previous deposit, or a generation of new and depletion of old active sites at the same rate. Because of the reduction in ASA, the oxidation rate of prepared composites decreases; therefore, the sample would last longer when exposed to rocket exhaust gases.

ACKNOWLEDGEMENTS

I want to thank Dr. Ismail for all the help he has given me over the past two years. He has spent a great deal of time instructing and teaching me about carbons and many other items he finds valuable in life such as time optimization. I admire his enthusiasm for carbon research.

Dr. Wesley Hoffman, Mr. Marlin Vangsness, Mr. Lester Tepe, and Mr. Wayne Roe have helped me considerably as they have generously donated their time to causes related to me on many occasions. I appreciate their concern and assistance.

I also wish to thank Mr. Richard Clark, Universal Energy Systems, the Air Force Office of Scientific Research, and Air Force Systems Command for making this summer possible, and helping me with difficulties as they came.

I. INTRODUCTION

Carbon carbon composites are important in manufacturing rocket nozzles, airplanes and other vehicles that need a high ratio of strength to weight. Consequently research into improving the properties of these composites is increasing and intensifying. Chemical Vapor Deposition (CVD) is one method that is being tested for its ability to improve carbon materials. CVD shows a promise in the upgrade of carbons and composites, but its mechanisms are not yet fully understood. Due to the importance of CVD in fabricating carbon composites, and therefore, the Air Force's concern about CVD, the Air Force Office of Scientific Research has been funding some of the research of chemical vapor deposition. For the past two years Dr. Ismail M. K. Ismail and Mr. Marlin Vangsness of the University of Dayton Research Institute have been studying the chemical vapor deposition of pyrolytic carbon on carbonaceous materials at the Air Force Astronautics Laboratory, while Dr. Wesley P. Hoffman AFAL/RKBA has been researching the CVD of TEOS on carbon substrates. (e.g., V3G, a graphitized carbon black).

In a graphite unit cell, the four valence electrons of central carbon atoms are bonded with other neighboring carbon atoms. These carbon atoms join together to form a basal plane resembling a hexagon. The hexagon is attached by its sides to other hexagons making the structure resemble that of a beehive, except that it is planar. The four valence electrons for all internal carbon atoms are used to bond with their neighbor atoms on the same plane, leaving none for three dimensional bonds. However, the valency of the external edge carbon atoms is not satisfied and, therefore, they can form chemical bonds with other elements, functional groups, radicals, and compounds. These sites are called active sites. Consequently, graphite is a long thin sheet of carbon. These sheets of carbon

are held together by weak van der Waals forces with an interlayer spacing of approximately 0.33538 nm. The unit cell or a graphite crystallite is shown in Figure 1. Graphitic materials are composed of several crystallites grouped together to form different types and shapes of particles. The orientation of the crystallites does not necessarily match the orientation of the particle or the carbon filament, however, the outer surface of most graphitic materials, with the exception of natural graphite, e.g., SP-1, is mainly composed of basal plane areas.

Figure 2 explains how the unit cells (crystallites) are generally oriented in three different materials; SP-1 Graphite, a graphitized carbon fiber filament, and a graphitized carbon black particle assumed to be spherical. At one extreme, the SP-1 flakes can be represented by short cylinders with their top and bottom areas much larger than the area at the sides of the cylinders. In this case, the basal planes run parallel to the top and bottom of the flakes, and only the sides of the cylinder have edge carbon atoms or active sites (Figure 2). At the other extreme, carbon fibers have insignificant cross-sectional areas at the top and bottom of the filaments. The crystallites at the outer surface of the filament are oriented with their basal planes running parallel to the filament axes (Figure 2). Therefore, most of the external area of the fibers is composed of basal planes with only active sites at both tips of the filaments and at points of defects and imperfections. Carbon blacks, on the other hand, also have their outer crystallite oriented with the basal planes parallel to the external crust (Figure 2). Because these blacks are composed of agglomerates of smaller particles, i.e., particles of the precursor from which the graphitized carbon black has been prepared, little is known about the orientation of the crystallites inside the larger particles.

II. OBJECTIVES

Dr. Ismail and Mr. Vangsness have executed extensive work on the CVD process on carbon fibers while Dr. Hoffman has been dealing mainly with a graphitized carbon black. This summer I worked with SP-1, a natural graphitic carbon powder.

My first objective with the present work was to systematically deposit pyrolytic carbon on the SP-1 graphite in a controlled manner and to specify the most appropriate experimental conditions for performing the tests. Secondly, the ASA and BET (total) areas of the starting material as well as of the composites prepared under different conditions were to be determined. The third goal was to propose a possible mechanism(s) of CVD on SP-1 graphite, and lastly to correlate, in a later stage, the mechanism proposed here with that previously proposed for CVD on carbon fibers.

III. EXPERIMENTAL

A. Material

The material used in the study was SP-1 graphite (purified natural flakes), supplied by the Union Carbide Corporation. This material is known to have a few ppm impurities; it is a non-porous carbon having a high density of 2.265 g/cc which is close to the theoretical value of 2.268 g/cc. The particle size of the flakes ranges from 1 to 250 microns with a mean diameter of 44.5 microns. A portion of the as-received material was activated in a muffle furnace at 923 K with circulating air until a 12.4% level of burn-off (B.O.) was reached.

B. Apparatus

The volumetric apparatus shown in Figure 3 was used to determine the active surface area of the SP-1 samples using oxygen chemisorption techniques. The system was also used to deposit layers of pyrolytic carbon on the surface of the material, a procedure called the chemical vapor deposition. With this apparatus a sample is placed in a quartz boat, and is positioned at the center of the quartz reactor. The reactor is connected to a manifold, which is in turn connected to three pumps (roughing, turbo-molecular, and vacion) , two pressure transducers, a mass spectrometer, two gas bulbs holding oxygen and methane, and a cold trap for collecting CO_2 during a chemisorption run. The transducer heads, mass spectrometer, furnace controller, and thermocouples are all connected to a multiplexer which is attached to a micro-computer. For most of the experiments the concentrations of gaseous products and system pressure can be monitored at high speeds using the Labtech Notebook® software.

C. Procedures

Before a sample was exposed to oxygen or methane, it was evacuated in the system to approximately 10^{-6} Torr, and then heated from room temperature to 1273 K. The sample was cleaned this way for 2 - 3 hours. If an ASA measurement was to be taken, the sample was then cooled to the designated isothermal temperature of 573, 673, or 723 K, and then injected with approximately 5 Torr oxygen. The sample was then allowed to chemisorb oxygen for 16 or 64 hours. After chemisorption, i.e., after the formation of chemical bonds between the carbon active sites and oxygen molecules, the excess oxygen

was removed by pumping, and the sample was heated at 20 K/min from the designated chemisorption temperature to 1223 K in thirty minutes. The sample was then held at this temperature for two hours during which the carbon-oxygen functional groups, which were formed during the previous chemisorption step, decomposed to yield a mixture of CO and CO_2. While the former gas was allowed to expand in the reactor and system manifold, the latter gas was collected in a cold trap immersed in a liquid nitrogen bath. At the end of this desorption step, the pressure of CO and CO_2 was measured, and the active surface area was then calculated based on the number of moles liberated as CO and CO_2.

The same system was also used to chemically deposit layers of pyrolytic carbon on the surface of the sample. After a sample had been cleaned at 1273 K, in the manner described earlier, it was injected with a predetermined dose of methane (the amount of gas needed to deposit the desired number of pyrolytic carbon layers). Since the reactor was kept at 1273 K, the C-H bonds of methane molecules broke producing hydrogen gas, solid carbon, and other larger polymeric molecules and radicals. The carbon deposited on the sample and the buildup of successive layers on the substrate continued. By knowing the starting and final pressure of the system, the number of micromoles of methane consumed was computed, and the actual number of layers of deposition was determined.

The total surface area of the samples was determined using Kr adsorption techniques at 77 K and the Braunauer, Emmett, and Teller (BET) equation; assuming 0.195 nm^2/Kr atom. Prior to the adsorption measurement, the samples were cleaned at 423 K for 4 hours under vacuum.

IV. RESULTS

Before actual and reliable CVD and ASA experiments could be run, the proper experimental conditions had to be specified. These conditions (e.g. temperature and time) had to make efficient use of time, i.e., the chemisorption reactions were taking place overnight and the desorption measurements were performed the next day. The chemisorption temperature had to be low enough so that the structure of the material was not changing but high enough to ensure the effective utilization of time. Several preliminary ASA measurements were ran to define the optimum conditions (Table 1). As the temperature and chemisorption time increased to did the ASA until a constant value was reached. The lowest temperature and the shortest time that gave an acceptable ASA value on SP-1 graphite were 673 K and 16 hours (Figure 4).

After the experimental conditions for ASA were established, the other experiments could begin. First the ASA of the SP-1 sample at 12.4% B.O. with no CVD layers was determined. Next, one layer, equivalent to one ASA, was chemically deposited on the sample. Thirdly, the ASA using oxygen chemisorption was determined. Another 1.7 ASA equivalent layers were deposited on the sample, and the ASA was again performed. This cycle was repeated several times until 542 layers of ASA equivalents were deposited (Table 2). After two equivalents were deposited on the sample, the ASA became constant because the deposition of additional layers showed negligible effects on the ASA. The starting ASA of the activated sample (i.e., before deposition) was 0.24 m^2/g, but it dropped and became constant at 0.155 ± 0.15 m^2/g after the deposition of two or more CVD layers. Occasionally, after the ASA was taken and before the next VCD layers were added, BET experiments of the sample would be performed.

When the as-received SP-1 sample was activated in the muffle furnace to 12.4% B.O., the ratio of ASA to BET rose (Table 3). When the activated sample with or without CVD layers were tested, the samples seemed to keep a relatively constant ratio of ASA to BET (Table 3).

Occasionally some of the samples with CVD layers were observed and photographed by a scanning electron microscope (SEM). In this regard, the assistance of Mr. Thomas Owens was highly appreciated. After 205 CVD layers were deposited on the sample, the particles looked to be similar in shape and size to the starting particles. However, tiny patches of carbon deposit can be seen on the surface of the particles, but not many. This means that pyrolytic carbon was depositing, in part, on the basal planes of the substrate. A few particles were also grouped together to form a particles of larger size. Clearly, as the photographs in Figure 5 show, the particles are connected together side by side. This indicates that pyrolytic carbon was also depositing on the active sites. After 277 ASA equivalent layers were a little larger. The last SEM photograph was taken after the sample had 417 ASA equivalents layer had been deposited. The particles were agglomerated together.

V. DISCUSSION

The ASA of SP-1 12.4% B.O. with no CVD layers deposited is 0.25 m^2/g. After one layer has been deposited the ASA drops to 0.21 m^2/g. This initial drop seems to be caused by the pyrolytic carbon depositing on the active surface area. The edge carbons each have an extra valence electron with which to react. Methane cracking yields several

radicals either atomic or molecular and large polymeric groups. It is therefore feasible for a CVD carbon to bond with two edge carbon atoms. Consequently, the ASA decreases. Eventually, after two layers of deposition, either all the edge atoms that had close neighbors are bonded to each other through the pyrolytic carbon radicals, or the new ASA is being generated at the same rate the old ASA is being depleted. For example, if we started with 20 edge atoms that were side by side and at the proper angles, we could feasibly finish the CVD with 10 active atoms.

After two or more layers of pyrolytic carbon deposition, the ASA became constant. Either all of the edge atoms who could bond, with a neighbor or with radicals or any other carbon in the near region to a pyrolytic carbon, have done so, or the ASA is generating and disappearing at the same rate. Most of the remaining active sites, are those of the pyrolytic carbon. Consequently, the new ASA is first composed of both the original ASA and the new ASA generated by the pyrolytic carbon deposition.

With more CVD layers added, the pyrolytic carbon deposits itself on this new ASA. Consequently, the same ASA pattern is repeated and repeated creating a constant ASA independent of the extent of deposition. The duplicating pattern creates a chain of carbon that grown in several directions. Every particle has its own growing chains, and when the chains get long enough they meet with the chains of other particles. Consequently, the chains may bond together, and the particles would ultimately agglomerate until all the voids between particles are completely blocked.

As seen in the fifth figure, there are darker carbon patches on some basal planes of the SP-1 with 417 equivalent layers of CVD. This seems to be due to the deposition of

pyrolytic carbon on the surface. The type of carbon that deposits on the basal plane is presumably not the same as the larger molecular radicals that is bonded to the ASA. The former carbon is stable and unreactive, like soot. Because the basal plane carbon atoms are not originally active, this type of deposition does not effect the ASA, following true with the constant ASA.

VI. CONCLUSIONS

Chemical vapor deposition reduces the active surface area of SP-1 12.4% B.O. and then keeps it at a constant level. (CVD does not deplete the original ASA entirely). The value of ASA is kept constant by either a chaining mechanism that also agglomerates the particles, or by a generating of new active sites at the same rate they are covered. Because CVD reduces the ASA, the sample becomes more stable to oxidation. Consequently, when the sample is subjected to higher temperatures and or concentrations of attacking gasses, it will oxidize less rapidly. CVD will help to preserve the life of the carbon sample.

VII. RECOMMENDATION

In order to establish if the SP-1 particles will agglomerate completely together after many CVD layers are added, or if the particle will become completely blocked off, the experiments should be carried out longer. The CVD runs, ASA measurements, BET measurements, and SEM photographs could establish this if continued until several thousand layers of deposition was reached.

VIII. REFERENCE

I. M. K. Ismail, "Structure and Active Surface Area of Carbon Fiber", Carbon 25, 653 (1987).

Table 1: ASA AS RELATED TO TEMPERATURE AND CHEMISORPTION TIME OF SP-1

RUN	TEMP	TIME	ASA(m^2/g)
1	673K	16 hrs	0.248
2	723K	16 hrs	0.238
3	623K	16 hrs	0.221
4	573K	64 hrs	0.204
5	573K	16 hrs	0.187
6	673K	16 hrs	0.219
7	723K	16hrs	0.244

TABLE 2: ASA OF SP-1 12.4% B.O. AS COMPARED TO THE # OF CVD LAYERS

# OF CVD LAYERS	ASA(m^2/g)
0	0.24
1	0.21
2.7	0.14
6.3	0.15
51.4	0.17
113	0.16
205	0.14
297	0.14
417	0.15
542	0.14

Table 3: ASA AND BET COMPARISONS OF SP-1 12.4% B.O. WITH A VARYING NUMBER OF CVD LAYERS

SAMPLE	CVD EQUIVALENT LAYERS	ASA (m^2/g)	BET (m^2/g)	$\frac{ASA}{BET}*100$
0	0	0.05	1.98	2.4
12.4	0	0.24	3.81	6.3
12.4	6.3	0.15	--------	-----
12.4	113	0.15	--------	-----
12.4	297	0.14	2.5668	5.5
12.4	417	0.15	2.2259	6.7
12.4	542	0.14	2.3640	5.9

FIGURE 1
THE UNIT CELL OF GRAPHITIC CARBONS

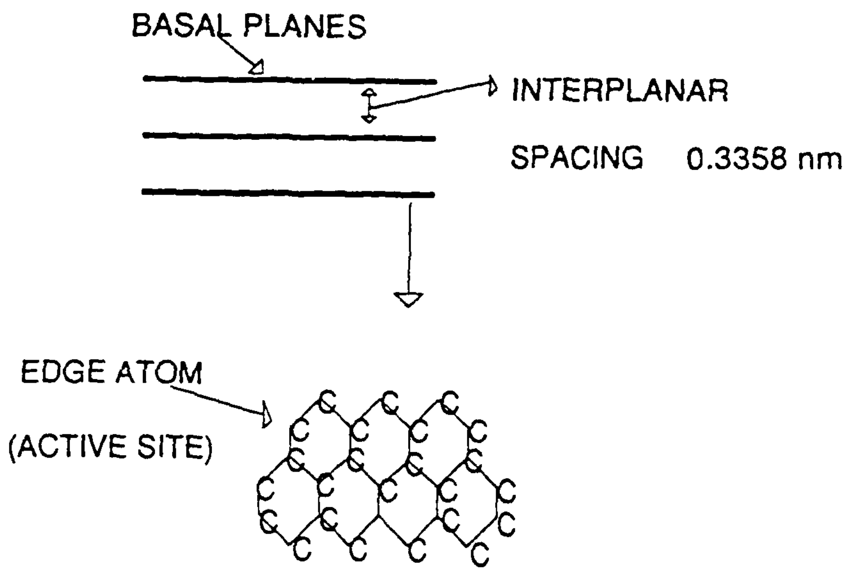


FIGURE 4

DEPENDENCE OF SP-1 ACTIVE SURFACE AREA ON OXYGEN CHEMISORPTION TEMPERATURE AT A FIXED CHEMISORPTION TIME (16 HOURS).

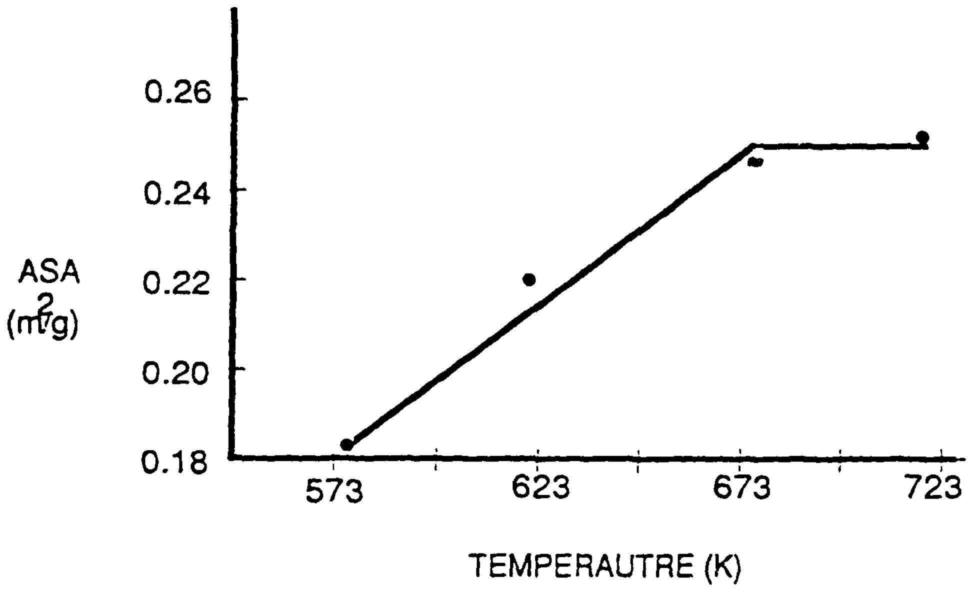
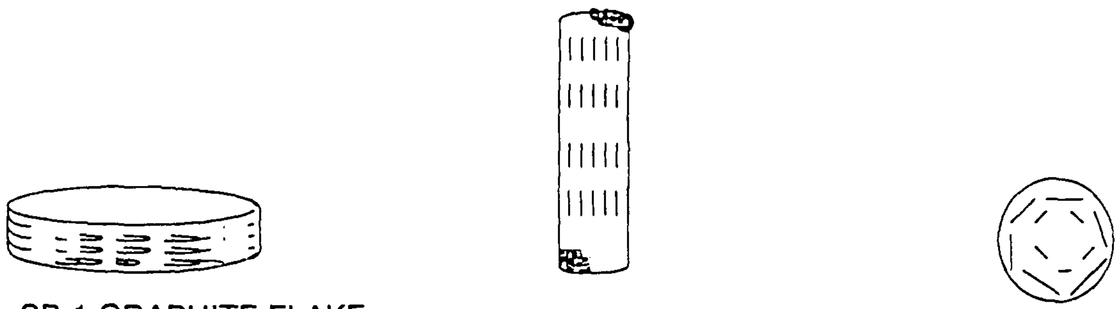


FIGURE 2

DIFFERENT FORMS OF GRAPHITIZED CARBONS USED FOR CVD STUDIES

1. SP-1 GRAPHITE: FLAKES (SHORT WIDE CYLINDERS)
2. CARBON FIBER: CYLINDER WITH INDEFINITE LENGTH
3. CARBON BLACK: SPHERICAL (E.G. V3G)

BET SURFACE AREA



SP-1 GRAPHITE FLAKE
MAINLY AREAS OF TOPS AND BOTTOMS OF THE CYLINDER

CARBON FILAMENT
MAINLY AREA OF THE SIDES OF THE CYLINDER

V3G PARTICLE
AREA OF THE SPHERE

ACTIVE SURFACE AREA

DENOTES ACTIVE SITE

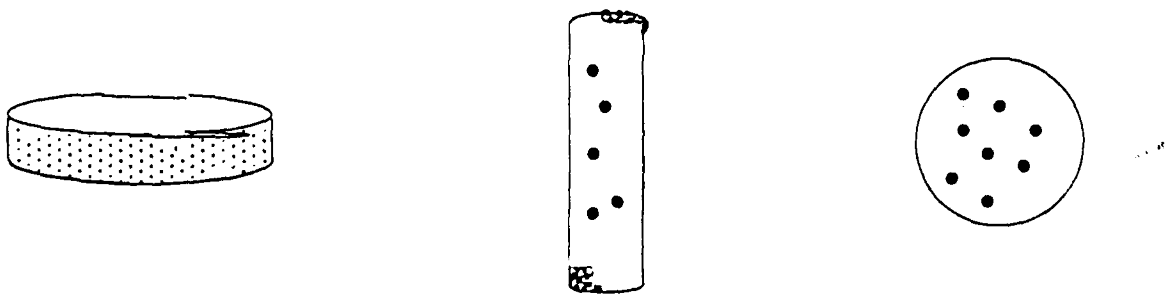


FIGURE #3: APPARATUS USED FOR CVD STUDIES AND FOR MEASURING THE ACTIVE SURFACE AREA OF THE MATERIALS

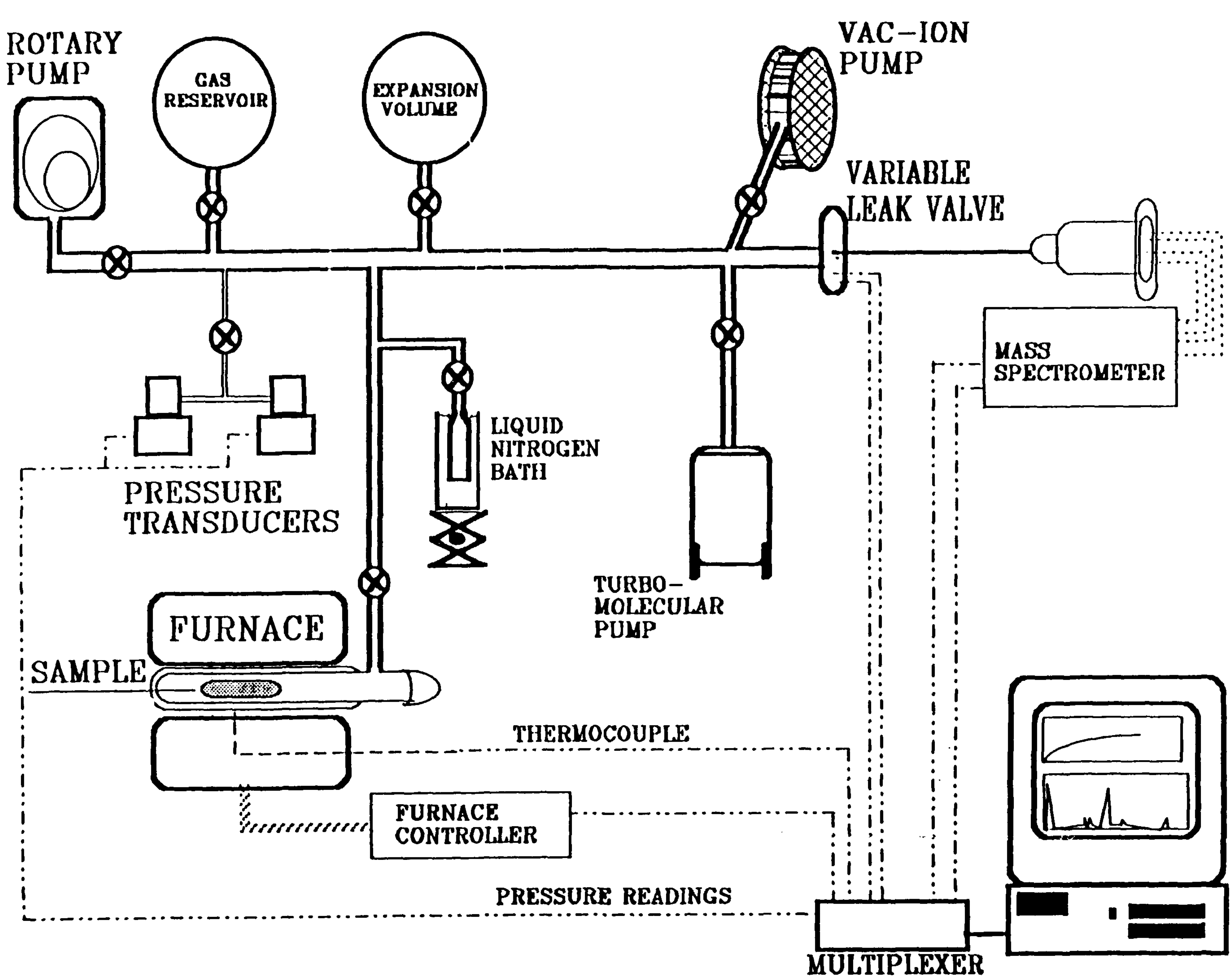


FIGURE #5

SCANNING ELECTRON MICROSCOPE PHOTOGRAPHS
OF SP-1 GRAPHITE 12.4% B.O. WITH 417 ASA
EQUIVALENT CVD LAYERS.

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

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FINAL REPORT

DAMPING OF LARGE SPACE STRUCTURES

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Date :	2 September 1988
Contract No :	F49620-88-0053

DAMPING OF LARGE SPACE STRUCTURES

by

Marie Webb

ABSTRACT

The damping of Large Space Structures is an issue being dealt with at AFAL. My work involved the characterization of damping through experiments performed here at the laboratory. I was able to be involved in many aspects of the experimentation. This summer's experience proved to be a good opportunity to gain knowledge in the field of engineering.

ACKNOWLEDGEMENTS

I wish to thank the Air Force Systems Command, Air Force Office of Scientific Research, and the Air Force Astronautics Laboratory for their sponsorship of the College Science and Engineering program. I would like to mention Universal Energy Systems for their administrative efforts to this program. To my USAF Researcher, Lt Tim Strange, I also wish to extend thanks for providing the opportunity to work in an enjoyable environment.

I. INTRODUCTION:

Entering my senior year in Chemical Engineering at the University of California, Los Angeles I sought summer employment which would provide me with a real world engineering education. Although my primary interests lie outside the field of space structures previous work experience here at the Astronautics Laboratory led me to do my summer research in this area.

With the advances in the Strategic Defense Initiative large space structures are in great demand, and the section with which I worked is concerned with the experimentation of such structures to examine their structural dynamics.

II. OBJECTIVES OF THE RESEARCH EFFORT:

In order to advance in the field of Large Space Structures many aspects of their behavior must be investigated. One concern is the modelling of such structures. My intentions for this summer research period were to become familiar with various modelling techniques, and understand the concepts behind the in-house work done by the Vehicle Systems Division, Subsystems Branch.

I was involved with the characterization of damping of structures through experimentation.

III. Background

The need to put Large Space Structures in orbit is increasing significantly, with the technologies such as Space Based Radar. The structures must have the ability to maintain their shape while encountering both on-board and environmental disturbances. This requirement is difficult to meet due to the fact that adding weight to the system, in order to strengthen the structure, will increase its cost. Therefore structure's integrity must be predicted, and the structural flexibility accounted for in the attitude control system design in order to achieve satisfactory performance of the spacecraft.

In this experiment our efforts were to characterize damping of such a structure. To do this we observed the behavior of a cantilevered beam, which was excited by a magnetic resonator, then allowed to dampen.

IV. THEORETICAL MODELLING OF THE BEAM

The following analysis is taken from Large Space System Design, Ref 1.

To study a damped system we chose the Euler-Bernoulli beam structure for its minimum complexity, to enhance insight into analysis methodology. The assumptions for this beam include bending in one plane only, negligible shear deformation and rotary inertia effects, and isotropic properties, such as uniform mass density and a constant modulus of elasticity.

The equation for the beam is given by:

$$\rho \frac{\partial^2 y}{\partial x^2} + E I \frac{\partial^4 y}{\partial x^4} = f \qquad [1]$$

where ρ = mass/unit length

f = force on the beam

E = Young's modulus of elasticity

I = Moment of Inertia

and the axes and properties of the beam are as shown in figure 1.

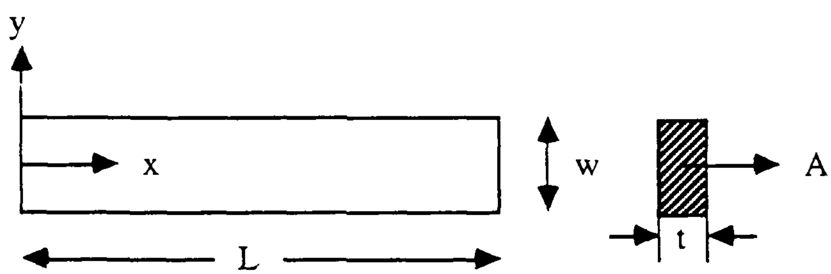

figure 1: Beam

Taking $y(x, t) = \Psi(x)\, q(t)$ [2]

and assuming a solution to the differential equation:

$$\psi(x) = A \cosh \beta x + B \sinh \beta x + C \cos \beta x + D \sin \beta x \qquad [3]$$

The form of Ψ (x) is good for all boundary conditions, but the values of A, B, C, D, and β depend on the particular boundary conditions. The cantilevered beam, which is attached at x = 0, will be considered here.

The boundary conditions for a cantilevered beam are given by:

$$\Psi(0) = 0$$

$$\Psi'(0) = 0$$

$$\Psi''(1) = 0$$

$$\psi'''(1) = 0$$

Then,
$$\psi'(x) = A\beta \sinh \beta x + B\beta \cosh \beta x - C\beta \sin \beta x + D\beta \cos \beta x \qquad [4a]$$

$$\psi''(x) = A\beta^2 \cosh \beta x + B\beta^2 \sinh \beta x - C\beta^2 \cos \beta x - D\beta^2 \sin \beta x \qquad [4b]$$

$$\psi'''(x) = A\beta^3 \sin \beta x + B\beta^3 \cosh \beta x + C\beta^3 \sin \beta x - D\beta^3 \cos \beta x \qquad [4c]$$

which can be expressed in matrix form as:

$$\begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ \cosh \beta l & \sinh \beta l & -\cos \beta l & -\sin \beta l \\ \sinh \beta l & \cosh \beta l & \sin \beta l & -\cos \beta l \end{bmatrix} \begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix} = \hat{0} \qquad [5]$$

The coefficient determinant is set equal to zero and solved, to give the nontrivial solution:

$$\begin{bmatrix} 1 & 0 & 1 \\ \sinh \beta l & -\cos \beta l & -\sin \beta l \\ \cosh \beta l & \sin \beta l & -\cos \beta l \end{bmatrix} + \begin{bmatrix} 0 & 1 & 1 \\ \cosh \beta l & \sinh \beta l & -\sin \beta l \\ \sinh \beta l & \cosh \beta l & -\cos \beta l \end{bmatrix} = 0 \qquad [6]$$

$$\cos^2 \beta l + \sin^2 \beta l + \sinh \beta l \sin \beta l + \cosh \beta l \cos \beta l$$
$$-(-\cosh \beta l \cos \beta l + \sinh \beta l \sin \beta l) + \cosh^2 \beta l - \sinh^2 \beta l = 0 \qquad [7]$$

Thus, the nontrivial solution for the cantilevered beam is:

$$\cosh \beta l \cos \beta l + 1 = 0 \qquad [8]$$

Solving for values of β (see table 1 for values) and solving equation (5) yields:

$$C = -A$$

$$D = -B \qquad [9]$$

By substitution:

$$A \cosh \beta l + B \sinh \beta l + A \cos \beta l + B \sin \beta l = 0 \qquad [10]$$

$$B = \frac{A(\sin \beta l - \sinh \beta l)}{(\cos \beta l + \cosh \beta l)} \qquad [11]$$

For the cantilevered beam, the mode shape of the nth mode is described by the equation:

$$\psi_n(x) = A_n \left[\cosh \beta_n x - \cos \beta_n x + \frac{\sin \beta_n l - \sinh \beta_n l}{\cos \beta_n l + \cosh \beta_n l} (\sinh \beta_n x - \sin \beta_n x) \right] \qquad [12]$$

The solution for the frequencies (ω_n) is given by:

$$\omega_n = (\beta_n)^2 \left(\frac{\pi}{l}\right)^2 \sqrt{\frac{EI}{\rho}} \qquad [13]$$

Table 1. VALUES OF β FOR CANTILEVERED BEAMS

Mode	β
1	0.597
2	1.494
3	2.5
4	3.5
5	4.5
6	5.5
7	6.5
8	7.5
9	8.5
10	9.5

V. DAMPING

The following discussion on damping is taken form Ref 2, Applied Mechanical Vibrations, to give further insight into our analysis.

The displacement of an underdamped system is a sinusoidal oscillation with decaying amplitude. A quite useful property of an

underdamped system can be obtained by comparing the amplitudes of any two successive cycles of the displacement. The amplitude of the ith cycle, which occurs at t_i, is given by the following expression:

$$x_i = Xe^{-\zeta\omega t} \qquad [14]$$

The amplitude, x_{i+1}, of the next cycle occurs one period later, at $t_i + \tau$, and is given by

$$x_{i+1} = Xe^{-\zeta\omega(\tau_i + \tau)} \qquad [15]$$

The ratio of successive amplitudes is then

$$\frac{x_i}{x_{i+1}} = \frac{Xe^{-\zeta w t_i}}{Xe^{-\zeta\omega(\tau_i + \tau)}} = e^{\zeta\omega\tau} = \text{constant} \qquad [16]$$

Since the amplitudes used to obtain this result were chosen arbitrarily, Eq (16) shows that the ratio of any two successive amplitudes is constant. Most commonly, the rate of decay of amplitude is expressed as the natural logarithm of the amplitude ratio, known as the logarithmic decrement and denoted by δ. Therefore,

$$\delta = \ln\frac{x_i}{x_{i+1}} = \ln e^{\zeta\omega\tau} = \zeta\omega\tau \qquad [17]$$

Substituting $\tau = 2\pi / \omega_d = 2\pi / \omega\sqrt{1-\zeta^2}$ gives

$$\delta = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}} \qquad [18]$$

Note that if ζ is small, then $\delta \cong 2\pi\zeta$.

The logarithmic decrement can also be obtained from the amplitudes of nonsuccessive cycles. If we form the ratio of amplitudes x_i and x_{i+1}, where n is any integer, we have

$$\ln \frac{x_i}{x_{i+n}} = \ln \frac{Xe^{-\zeta\omega t_i}}{Xe^{-\zeta\omega(t_i + n\tau)}} = n\,\zeta\omega\tau = n\,\delta \tag{19}$$

This expression is useful for measurement purposes when it may not be feasible to measure successive amplitudes or when an average is to be obtained from several amplitude ratios.

For experimental purposes, the logarithmic decrement is useful in determination of system damping. If any two amplitudes of a damped oscillation are obtained by measurement, the logarithmic decrement can be obtained with Eq (17) or Eq (19) as appropriate. With δ known, Eq (18) is used to obtain the damping factor as

$$\zeta = \frac{\delta}{\sqrt{(2\pi)^2 + \delta^2}} \tag{20}$$

This approach is particularly useful where the actual damping mechanism in a system is not precisely known.

VI. TYPE OF WORK PERFORMED

The initial aspects of my duties were to draft blueprints of the experimental set-up using Teknic. , a drafting package. Once the designs were available we were able obtain the materials needed, and conform them to the experimental specifications.

Also, using Nastran and Patran we modelled the beam, to give us expected frequencies and mode shapes. This was done to facilitate the placement of proximity sensors, used to measure displacement, and the magnetic resonators, along the beam's length.

One of the beams to be tested was to be made of a composite material. I did research into the field of composites to understand the design of such a beam. I spent a great deal of time with the workers in the Composites Laboratory to better understand the parameters involved in composite structures.

Experimentation has begun, and a steel beam has been tested. However, with only one beam having been tested I was unable to draw any conclusions.

VII. RECOMMENDATIONS

The testing being done at AFAL is important to our future space systems, and I feel I have learned a great deal about space structures.

The CSEP provides undergraduates with opportunity to experience the real world of engineering while learning valuable working skills. I feel that my summer experience has helped me to develop important interpersonal skills, and has encouraged me to continue with my engineering education, with some knowledge of what the field of engineering entails.

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FINAL REPORT

SOLID ROCKET MOTOR DATA BASE

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University:	San Diego State University
Research Location:	Air Force Astronautics Laboratory, RKBR
USAF Researcher:	Mr. Steven Sasso
Date:	August 21, 1988
Contract number:	F49620-88-C-0053

ABSTRACT

The need for reliable and handy reference material is a universal one in any research related environment, the Motor Technology section at the Air Force Astronautics Laboratory is no exception. The reference material that I was concerned with was not inaccessible but it was buried in various technical manuals, many of which were hundreds of pages long. My main project was to compile the pertinent information of certain solid rocket boosters in an easy to use and consistently formatted data base.

I. INTRODUCTION

This summer, I was fortunate enough to be employed at the Air Force Astronautics Laboratory in the Motor Technology Section. The Motor Technology Section oversees research and development contracts with civilian aerospace companies as well as conducting in-house research on advanced technologies.

Currently, I am a mechanical engineering student at San Diego State University where I hope to gain a specialization in propulsion. As one may imagine, I was particularly pleased with my assignment in the Motor Technology Section where I was exposed not only to the governmental environment of research and development, but also the civilian world as well. This experience has helped me narrow down some choices for my pending senior project which I hope to be able to work on in conjunction with the Air Force Astronautics Lab.

II. OBJECTIVE

In dealing with various contractors, the Motor Technology Section has accumulated a wealth of information on various systems. Unfortunately, this agglomeration of data exists in many different formats, predominantly in technical manuals sometimes numbering as many as seven hundred pages long. In this form, it was found that quick referencing was a virtual impossibility and referencing specific

information from these manuals was impractical. A localized and consistently formatted data base was seen as the obvious solution to the uncompiled and scattered reference material.

I was assigned the task of creating a data base consisting of the various specifications of individual solid rocket motor systems. The data base had to be consistently formatted for each individual solid rocket booster. As well as consistency, the data base had to be relatively in-depth and its information needed to be accessible for task specific manipulations such as adding numerical data and grouping certain descriptions. These requirements later helped me to make an important decision on which type of software I would use to run the data base.

III. APPROACH TAKEN

Having been assigned the task of compiling the data base, I set out to determine the most efficient manner to proceed with the tools that I had available to me. I looked at various pieces of commercial software of which I found two to be specifically suited to the project, Lotus 1-2-3 and Data-Base Three Plus. I choose Data-Base Three Plus because of it's unique ability to filter, format and manipulate data on command. This software's versatility seemed to be tailor made for compiling this type of a data base since one of the main requirements was to enable the information to be used for analysis and quick referencing.

The first major step taken towards reaching the final product was learning to use the software as I then had no previous experience. I

acquired the software's accompanying user's manual and began learning to use the software as I saw fit to accomplish the task.

After I acquired a working knowledge of the software, I set about creating a format for the data base. I had to be careful to choose a format that would be common to as many systems as possible. The format I created is a list of performance and characteristic parameters in two to three columns depending on the number of stages on a particular booster. The information is called out according to it's classification and grouped in one of the following subheadings: general booster information, propellant characteristics, case characteristics, nozzle parameters and weight specifications.

Finally, the data was extruded from the various technical manuals and inserted into the formatted data base. It was in this phase of the project that I had the most difficulty with. Much of the required information was too specific in nature and was not listed in any form in the manuals that I had available. For most of the systems, this was not a problem as I was able to utilize other sources of information. This was not the case for about three of the boosters, all three of which were from the same family, the Titans and considerable time was spent locating the appropriate information.

IV. RESULTS OF APPROACH

Learning Data Base Three Plus was not as timely a task as I had expected it to be on the outset of the summer, probably due to the software's user friendliness and easy to use menu driven workstations. A

more timely matter was creation an acceptable format that would more or less be adhered to by each solid booster and its' specific characteristics. Mr. Steven Sasso helped me to decide on a final format that he thought would be acceptable to everyone that would be using the data base, taking into consideration their individual needs.

The format of the data base has a top-down structure that covers general booster information and then gradually becomes more specific and detailed as the user requires. The boosters are represented by their individual characteristics which are arranged according to the system or component that that they most directly relate to. A separate format is used for the final cataloged printouts, this format concerned itself with margins, headings, titles and the like.

The task involving the most time was the actual researching or "digging" for information on the boosters. For most of the boosters, the information was accessible through materials stockpiled here at the lab. A few rocket motors did not fall into the well documented category. Specifically, information relating to the Titan family of boosters was not on hand and further inquiries had to be made. Mr. Sasso's associates at the Air Force Space Division were contacted and at the time of writing this report, the expected information has not yet arrived.

I have enclosed an example of perhaps the most reputable booster in the data base, the Morton Thiokol Solid Rocket Motor (SRM) that is currently being used on the Space Shuttle Transportation System.

V. RECOMMENDATIONS

The data base of solid rocket boosters will be used as a quick reference book that would yield immediate information in such situations as conferences, contract negotiations, and reference. Also, the data base is formatted so that numerical data may be mathematically manipulated and therefore be used to support studies such as cost and reliability analysis.

Obviously, the data base is most useful when it is most current. Since the format and call-out procedures have been established, the data acquisition and input portions are all that separates the engineering/management staff from continuing the compilation process thus keeping the data base current.

Finally, for anyone in need of this type of information handling, I cannot overemphasize the versatility of Data Base Three Plus. This software is quite powerful and has great organizational capability. I could not have produced this project in this manner without this program.

ACKNOWLEDGEMENTS

I would like thank the Air Force Systems Command and the Air Force Office of Scientific Research for providing me with the opportunity to work at the Astronautics Laboratory. I would like to thank Dick Clark and UES for their contract support. Mr. Clark especially did an exemplary job of organizing things on this end. Wayne Roe also deserves thanks for his work with the UES students throughout the summer.

I would also like to thank Dr. Hawk for bringing me aboard his division this summer. Finally, I would like to extend my gratitude to Steve Sasso who helped me with every major obstacle that I encountered this summer. Steve also provided me with an insight to the "real world" of engineering and has instilled in me a new confidence in this exciting field.

SPACE SHUTTLE SOLID ROCKET MOTOR

****

PROPELLANT SPECIFIC IMPULSE(lb-sec/lbm)	262.2/267.0
MEOP (psia)	946.20
BURN TIME/ACTION TIME (sec)	113.2/122.4
TOTAL IMPULSE (lbm-sec)	296400000
MAXIMUM THRUST (AVERAGE) (lbf)	3310000
ACTION TIME AVERAGE THRUST (lbf) EE6	2.59
MINIMUM OPERATIONAL TEMPERATURE(deg F)	40
MAXIMUM OPERATING TEMPERATURE(deg F)	90
MINIMUM STORAGE TEMPERATURE (deg F)	32
TOTAL BOOSTER LENGTH(in)	1513.38
MAXIMUM CASE DIAMETER(in)	146.00
CASE L/D	10.37
TOTAL CASE LENGTH(in)	1388.56
FORWARD MOTOR SEGMENT	327.5
MID MOTOR SEGMENT(in)	320.00 (2)
AFT MOTOR SEGMENT(in)	489.00
CASE MEMBRANE THICKNESS(in)	0.459
TOTAL NOZZLE LENGTH (in)	167.20
EXPANSION RATIO	7.16:1
PROPELLANT WEIGHT(lbm)	1110136.00
CASE WEIGHT(lb)	97536.00
FORWARD SEGMENT WEIGHT(lbm)	26226.00
MID SEGMENT WEIGHT(lbm) (2)	21367.00
AFT SEGMENT WEIGHT(lbm)	28576
INSULATION WEIGHT(lb)	18670.00

SPACE SHUTTLE SOLID ROCKET MOTOR
****

LINER WEIGHT (lbm)	1346.00
NOZZLE FWD. SECTION WEIGHT(lbm)	17160.00
TVA WEIGHT(lbm)	2261.52
AFT SKIRT WEIGHT(lbm)	1200.00
EXTERNAL INSULATION WEIGHT(lbm)	55.00
TOTAL INERT WEIGHT(lbm)	145614.00
TOTAL LOADED WEIGHT (lbm)	1255750.00
CASE TYPE	D6AC STEEL
CASE VENDOR	LADISH STEEL
CASE LENGTH(in)	1388.56
FORWARD MOTOR SEGMENT(in)	327.50
MID MOTOR SEGMENT(in)	320.00
AFT MOTOR SEGMENT(in)	489.00
CASE MIMIMUM THICKNESS(in)	0.459
CASE MAXIMUM THICKNESS(in)	146.00
MINIMUM INSULATION THICKNESS(in)	0.03
FORWARD SECTION MINIMUM(in)	0.03
MID SECTION MINIMUM(in)	0.05
AFT SECTION MINIMUM (in)	0.20
COMPOSITE CASE	
EXPANSION RATIO, INITIAL(Ae/AT)	7.16:1
THROAT AREA, INITIAL(sq in)	2278.00
EXIT DIAMETER, INITIAL(in)	145.65
SUBMERGENCE RATIO {d/1}	0.24
INITIAL ANGLE(deg)	24.60

SPACE SHUTTLE SOLID ROCKET MOTOR

****

EXIT ANGLE(deg)	10.46
TOTAL NOZZLE LENGTH (in)	167.20
LENGTH EXTERNAL TO CASE (in)	114.40
THROAT TO FLANGE (in) {d}	29.35
NOZZLE CONSTRUCTION (type of weave)	TAPE WRAP
EXIT CONE CONSTRUCTION (type of weave)	CARBON PHE
EXIT CONE WEIGHT (lbm)	5883.00
FIBER TYPE	CARBON PHEN.
IMPREGNATION METHOD	PRE-PREG
PROPELLANT CLASSIFICATION	1.3
PROPELLANT DESIGNATION	TPH-1148
PROPELLANT FORMULATION	
HB POLYMER and ECA TYPE II (%)	14.0
ALUMINUM(nonspherical)	16.0
IRON OXIDE TYPE II (%)	0.3
AP (%)	69.7
BALLISTIC CHARACTERISTICS	
BURN RATE AT 1000 psi and 60 deg F(in/s)	0.425
BURN RATE EXPONENT	0.35
DENSITY(lbm/cu.in)	0.064
TEMPERATURE COEEFICIENT OF PRESSURE(%/F)	0.11
CHARACTERISTIC EXHAUST VELOCITY(ft/sec)	5062.00

1988 USAF-UES COLLEGE SCIENCE AND ENGINEERING PROGRAM

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FINAL REPORT

SUMMER RESEARCH EFFORT

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Date:	August 15, 1988
Contract No.:	F49620-88-C-0053

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ABSTRACT

The work done during my summer term at the Astronautics Laboratory was part of a larger research project at the lab. The stand which I designed as one of my projects at the lab is going to be used for a future test. Ten steps were performed during the design stage of this stand including a surveying task and an inspection of available I-beams at the lab. After the design modifications were complete I began work on another project related to the KHIT test. The analysis of the facility accelerometer data from the second static test firing is crucial to the completion of the entire project. Preliminary results concluded from the data have been published in a Vehicle Systems Analysis & Integration branch report. In addition to the two major projects I also performed work on two smaller projects which have yet to show any substantial results.

I. INTRODUCTION:

At the Air Force Astronautics laboratory, research is currently being conducted into the Kinetic Energy Weapon (KEW) aspect of the Strategic Defense Initiative. The purpose behind the KEW project is to allow interception and destruction of intercontinental ballistic missiles before their warheads can inflict unacceptable damage upon their intended target. The KEW will be launched in space from an orbiting platform and will use its own on-board propulsion and seeking systems to intercept the missile.

In order to reduce development costs, guidance and propulsion system designs are being tested on the ground. The Air Force Astronautics Laboratory Vehicle Systems division is studying the feasibility of one such design. The Kinetic Kill Vehicle Hover Interceptor Test (KHIT) program involves building a prototype of a KEW and testing its on-board systems. Thus far in the program, the KHIT vehicle has undergone two strap-down static tests. Data obtained from these tests will be analyzed and the results will be used in future testing and possible modifications to the vehicle. The next test in the program is a hover test in which the KHIT vehicle will perform a mission similar to one which a KEW would perform. A future test known as On-Target will test the seeking capabilities of the vehicle. On-Target is a follow-up test which will be performed should the hover test be successful.

I am a sophomore in the school of Aeronautical and Astronautical Engineering at Purdue University. Since my interests in the aerospace field lie in the area of propulsion, I was assigned to the Integration and

Analysis branch of the Vehicle Systems division which is responsible for the KHIT project.

II. OBJECTIVES OF RESEARCH EFFORT:

The project to which I was assigned involves the On-Target test. During the test a 5000 lb. thrust solid rocket motor will be fired nozzle up. The seeker on the vehicle will then track the motor plume and relay the data to a computer. A problem exists concerning the height of this target motor. The test requires the motor to be 19 feet above the ground in order for the KHIT vehicle to perform its tracking task. My project was to design a work platform to raise and support the motor, the thrust it generates, and the support team. Because the work on the test stand proceeded slowly, I also assisted various AFAL employees with their assigned projects. With the platform design near completion and much time remaining in my term of employment I was assigned to another project. This second major project involved the reduction and preliminary analysis of a portion of the data obtained during the second static tes' g of the KHIT vehicle. The results of this assignment were published in a Vehicle Systems report titled KHIT Static Test Data Analysis.

III.

The first action taken on my part towards the completion of my project was to obtain a detailed project description. My primary AFAL contact, Mr. Brian McKee, explained the problem with the On-Target test. I was shown the test stand location and introduced to several key project personnel. The preliminary task description indicated the need for a design of an entire work platform. Soon thereafter however, an existing work platform was

located. This platform, used to support a Titan solid rocket booster before undergoing testing, was similar in design to what the solution of the problem called for. After permission was obtained for the use of the platform, I began to make rough sketches of the necessary modifications. The next task at hand was to obtain the original blueprints of the Titan work platform. Tracking them down did not prove to be a problem, but obtaining copies did. Approximately two weeks passed before I received the copies. During these two weeks I worked on various smaller projects to keep myself occupied. These projects included modifying a Fortran program and using a Macintosh application to track satellites. After receiving the blueprints and examining them I noticed significant inconsistencies between the planned dimensions and actual measurements taken from the stand. In order to maintain the precision required in the problem description, actual measurements were used as opposed to the blueprint dimensions during the design stage. Because elevation of the test stand location was an integral part of the problem, I was required to perform a survey of the area in question. More rough drafts of the design modifications were completed incorporating all available relevant dimensions. One stipulation of the problem required the use of materials on-hand at the fabrication shop at AFAL. I took measurements of various I-beams in supply and decided which beams I was able to make use of. With the required information gathered I then transformed my rough sketches into the final modification design. The final step included taking the design to draftsmen for modification blueprints and coordinating the completion of the drawings.

IV.

As I mentioned earlier, while working on the On-Target project I completed a couple of smaller tasks. The first of these involved satellite tracking using a Macintosh application known as MacSat. The satellite's ephemeris, its set of orbital characteristics, was calculated using a program on the AFAL Vax computer system. This data was then entered into the MacSat input file and the satellite orbit propagated. Hardcopies of the plots were made to inspect for inconsistencies between expected and actual output. If the error was beyond the reasonable tolerance allowed, the data was re-configured slightly and the propagation performed once more. Since I only assisted Lt. Mike Dickey with his work, the results of my effort belong to him. The second of the minor projects I worked on used my knowledge of the Fortran programming language. Modifications to an existing Fortran program were desired to allow the operation of the program independent of another Vax program known as *Matrix-X*. After inspecting the original code, I decided upon the necessary modifications. Although the new code was not very complex, it involved file input of matrices and was therefore very difficult to debug. The modified code has been tested and will run as expected. The results of the output are not yet available as the final program is not completely ready to run.

V.

The second major project in which I was involved concerned the reduction of data obtained from the second static test firing of the KHIT vehicle. The data was from five accelerometers mounted in the test facility. A reading was received from each of three axes from every accelerometer. The data was sampled at 4166 Hz. for the entire 25 second test. After the data was transferred to the AFAL Vax computer system, I proceeded to change the

raw data into understandable units using the provided conversion factors. Plots of acceleration versus time were then constructed and hardcopies made. In addition, the Fast Fourier Transform utility in Matrix-X was used to identify the primary frequencies of vibration. Preliminary conclusions were drawn from visual inspection of the data plots. A final report on the data analysis was then drafted. This report and the results of the test in general will be studied further to assess the need for structural changes in the facility. Such changes may be necessary to obtain a facility which will not interfere with the hover test.

VI. RECOMMENDATIONS:

The final design for the work platform will be stable during the On-Target test firing. The modifications to the existing test stand should be completed as soon as possible in order for the On-Target test to remain on schedule. The facility accelerometer data from the second static test firing indicates that no major problems exist with the facility test structure. The data analysis of the second static test firing will continue in depth and the results of these efforts will be used to enhance the performance of the test facility.

ACKNOWLEDGMENTS

I would like to thank Air Force Systems Command, Air Force Office of Scientific Research, and the Air Force Astronautics Laboratory for the opportunity to work as a summer research fellow at Edwards Air Force Base. I would also like to thank everybody from whom I received assistance during my research period. The advice and guidance of Brian McKee, Dave Ductor, and Dave Barnhart was greatly appreciated. The insightful contributions of Lt. Mike Dickey, Chuck Dillon, and Brian Wallace were of immense help. The encouragement received in the Vehicle Systems office was more than well received.